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A RAND NOTE

FLEXIBLE URETHANE FOAMS AND CHLOROFLUOROCARBON EMISSIONS

William E. Mooz and Timothy Quinn

June 1980

N-1472-EPA

Prepared For The U.S. Environmental Protection Agency

Rand
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PREFACE

A theory advanced in 1974 suggested that emissions of fully halogenated chlorofluorocarbons (CFC) into the earth's atmosphere migrate upward to the stratosphere, where they take part in a series of reactions resulting in depletion of the ozone layer there. The consequences of ozone depletion were judged to be serious threats to human and animal life, plants, and the weather. As a result, the U.S. Environmental Protection Agency (EPA) took action to ban aerosol uses of CFC, and began a series of investigations into non-aerosol uses of these materials. Part of this effort was a study of the economic implications of regulating CFC emissions, performed by The Rand Corporation under Contracts PC 68-01-3882 and 68-01-6111. The results of that study are reported in Rand Report R-2524-EPA, Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications, by Adele R. Palmer, William E. Mooz, Timothy H. Quinn, and Kathleen A. Wolf, June 1980. Because R-2524-EPA deals with a large number of CFC uses, it is ponderous to use for readers interested in only one product area, such as flexible urethane foam. Also, the single-volume format of R-2524-EPA required that much of the data and procedures used in each product area be summarized.

The present report records the research in the single product area of flexible urethane foams. It serves as a detailed exposition of the data and of the methods used to proceed from the historical data to the analysis of policies that might reduce CFC emissions. It should be useful both to the large community of flexible-urethane-foam manufacturers and to persons in other fields who are interested in the methods of analysis used in a single product area. The economic aspects of regulation, which are treated in detail in R-2524-EPA, are dealt with in the present report only to the extent that they impinge upon the subject of flexible urethane foams. Questions concerning taxes on CFC and concerning marketable permits as economic incentives to reduce CFC emissions are not discussed here, and the reader is referred to R-2524-EPA.

SUMMARY

In 1974 a theory was advanced that postulated the depletion of the stratospheric ozone layer through reactions with chlorofluorocarbon (CFC) emissions on the earth. The results of this depletion could be changes in climate, and serious impacts on animal, vegetable, and human life. In response to this theory, aerosol uses of the CFC were essentially banned in the U.S. in 1978, and the Environmental Protection Agency (EPA) began a series of studies of the non-aerosol uses of the CFC.

This document deals with a specific product area that uses CFC--that of flexible urethane foams. These foams made their appearance about 1960. They are a cushioning material that can be made with characteristics ranging from the stiff support required of carpet underlay, to the softness found in the back of a comfortable easy chair. In addition, the material can be molded into any shape, or can be made in a bulk form called slabstock which can be cut to size as needed. The versatility of the product caused rapid penetration in furniture, bedding, and automotive seating applications, where it displaced springs, cotton bats, rubberized hair, felt, and other cushioning materials. As a result, the production of flexible urethane foams has grown from infancy in 1960 to a large industry. This industry made about 1300 million pounds of foam in 1977, and employed in the range of 13000-25000 people in plants located in the furniture centers of the country, in the areas close to automobile manufacturing, and in major population centers.

Flexible urethane foams owe their distinctive properties to their cellular nature, and these cells are produced by a blowing agent. CFC is a common blowing agent, and about 39 million pounds of CFC-11 were used and emitted during the production of foams in 1977. This amounts to about 13 percent of all U.S. CFC emissions at present, and projections indicate that this share of the emissions will remain essentially constant until 1990. Emissions from the manufacture of flexible urethane foams were the third largest source in 1977, and

they are projected to be the fourth largest source in 1990. Thus this product area requires careful analysis if it is desirable to reduce non-aerosol CFC emissions.

There are two methods of reducing CFC use and emissions from the manufacture of flexible foam. The first is to substitute an alternative blowing agent, in this case, methylene chloride. Methylene chloride is presently used by many slabstock foamers, but not by manufacturers of molded foam, where technical characteristics of the product have essentially precluded its use. There is the possibility of replacing more of the CFC used as a blowing agent with methylene chloride, but increased penetration of this substitute faces a number of obstacles. Some of these concern the ability to substitute in certain foam formulations, some concern the quality of the product, some concern the manufacturing scrap rate. Others have to do with perceptions and prejudices of individuals in the business, who for one reason or another would "rather fight than switch." And lastly, there is the question of the relative costs of manufacturing with one blowing agent versus the other. When all of these factors are combined, it appears that slabstock foamers who would now have the option of switching from CFC-11 to methylene chloride are presently willing to incur a raw materials cost penalty of 2 to 6 percent in order to retain the use of CFC. Even if all of these could be converted, apparently 25 percent of the CFC blown slabstock could not be converted for one reason or another, in the judgment of the industry.

Since the use of methylene chloride to blow molded foam is also precluded, the effect of a conversion of all the "eligible" slabstock to methylene chloride would reduce emissions by about 50 percent.

The second method of reducing CFC emissions is the recovery and recycle of the blowing agent during the manufacturing process. The method of doing this is known, used in other manufacturing processes, and appears applicable to flexible foam manufacture after the solution of some technical problems that are not judged as severe. Capital investment is required, and at present CFC prices the keys to the economics of the process are the ability to collect a large fraction of the emitted CFC, and to maintain a high average use rate, or capacity

factor, on the capital equipment. The first of these criteria, the collection efficiency, is controlled by the ventilation and exhaust system that is required on all foam lines for reasons other than CFC emissions. Indications are that well-designed systems may presently collect about 50 percent of the emitted CFC, and at least one patent suggests that over 80 percent could be collected.

The second criterion is a function of the plant production rate. Most plants have similarly sized equipment, and the production rate is controlled by the amount of time the equipment is operated. Thus, plants that have high production rates utilize their capital equipment more fully. Recovery equipment in large plants would also be utilized a greater percentage of the time than in small plants, and consequently the process would be attractive to large foamers sooner than to small ones.

At the present price of CFC-11, recovery and recycle of CFC appears economic for plants that use 1.5 million pounds or more of CFC per year if the capital equipment can be purchased ex-factory for $30 per cubic foot of gas per minute of capacity (CFM), and under conditions of a 4-year payback on the capital equipment. Roughly 50 percent of present CFC use for flexible foam manufacture is in plants of this size.

The emissions reduction potential of recovery and recycle is ultimately a function of the collection efficiency of the emitted CFC. Since recovery and recycle can be used for both slabstock and molded foam, emissions could be reduced by about 50 percent if the average collection efficiency was about 50 percent.

Either of these methods of reducing emissions could be mandated by regulation, but this study did not consider the substitution of methylene chloride as a candidate for mandate. Reasons for this are that if the mandate applied to all flexible foam, it would essentially constitute a ban on the manufacture of molded foam and on the 25 percent of slabstock that cannot be blown with methylene chloride. If the mandate applied to only the 75 percent of slabstock for which methylene chloride could be substituted, it might well be unenforceable, since in many cases plants would make both CFC blown and methylene chloride blown foams, and constant surveillance would be required to insure adherence to the regulation.

Recovery and recycle is considered an enforceable method of reducing emissions, since the presence of the equipment can be readily confirmed. Further, the costs are such that once the equipment has been purchased, it pays for the owner to use it. Mandated recovery and recycle also allows foamers to escape the mandate by switching blowing agents. Thus such a mandate might result in large plants installing the equipment, and small ones switching to methylene chloride.

Inducing higher CFC prices through either a tax or a marketable permit system also induces the use of these emissions reduction methods by making it profitable for a firm to either switch or to recover. Demand schedules show that the 50 percent emissions reduction that is possible by mandating either substitution or recovery can be induced by a price increase from 34 cents per pound for CFC-11 to $1.04 per pound. Moreover, higher price increases induce even further emissions reductions, with a reduction of about 80 percent occurring at a CFC price of about $1.52 per pound. The effects of still higher prices were not studied.

Detailed comparisons of the effects of mandates versus economic incentives, and discussions of the details of the economic incentives, are treated in detail in the summary report of this entire study, *Economic Implications of Regulating Chlorofluorocarbon Emissions from Nonaerosol Applications*, R-2524-EPA, Adele R. Palmer, William E. Mooz, Timothy H. Quinn, and Kathleen A. Wolf, June 1980.

ACKNOWLEDGMENTS

The data from which this study resulted came from a large number of firms. Manufacturers of precursor chemicals, blowing agent manufacturers and distributors, slabstock and molded foamers, furniture manufacturers, trade associations, and many others gave of their time and expertise, as well as of their data. Contacts were made in person, by telephone and mail, and, importantly, through an anonymously replied survey made possible by the Society of The Plastics Industry. Consequently, our debt of gratitude extends not only to very many organizations and individuals, but also to some who are anonymous. We cannot name them all, for they number in the hundreds, but we acknowledge here the efforts that were made in our behalf, and extend our thanks to those who helped.

The authors also thank their internal collaborators. Joyce Marshall typed the numerous drafts, Will Harriss made the report more readable through careful editing, and David Jaquette provided a perceptive technical review.

CONTENTS

I. INTRODUCTION

In 1974 a hypothesis was advanced that the atmospheric releases of chlorofluorocarbons (CFC) resulted in depletion of stratospheric ozone. The ozone layer in the stratosphere provides protection to the earth, and its depletion could result in changed weather, and undesirable effects on plant and animal life. As a result, the use of the CFCs for aerosol propellant was banned in late 1978, and the U.S. Environmental Protection Agency began a series of investigations into the non-aerosol uses of the CFCs. The work reported herein was performed as part of research into the economic effects of regulating these non-aerosol uses of the CFCs. Part of the research that is reported deals with non-traditional regulating mechanisms, specifically the use of economic incentives to reduce CFC emissions. The product area that is covered in this report is flexible urethane foams.

Flexible urethane foams are a cushioning material that has some resemblance to the "foam rubber" of the 1950's. It can be made in an extremely wide range of physical properties that allow it to be used in diverse applications. These physical properties can generally be related to the density of the material, with very low densities being the softest and most resilient, and with high densities being more resistant to deformation. The appeal of these characteristics put the material in direct competition with other cushioning materials, and today urethane foams have displaced substantial proportions of the use of cotton batting, coil springs, foamed latex rubber, rubberized hair, felt bats, and other traditional cushioning materials. As a result, flexible urethane foams are now an important component of furniture, automobile seats, carpet underlay, bedding, and other products where a durable and resilient material is required.

About 1300* million pounds of these products were manufactured in 1977, and the approximate breakdown among the various markets is shown in Table 1.

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*Based on estimates by chemical suppliers.

Table 1

DISTRIBUTION OF FLEXIBLE FOAMS USE AMONG FINAL PRODUCT MARKETS, 1977

Market	Percentage by Weight
Furniture	38
Transportation	29
Bedding	15
Prime carpet underlay	12
Packaging	2
Textiles	2
Other	2

SOURCES: Mobay Chemical Company (see Upjohn, 1977b); Mobay (1978); Olin Chemical Group, private communication.

The important characteristics of flexible foams are imparted by blowing agents, which form the holes (or cells) in the foam and give it its flexibility. In all flexible urethane foams, the primary blowing agent is carbon dioxide, which is formed by the reaction of water and TDI (toluene diisocyanate). Foams with lower densities than are possible by water blowing (as it is called) require an auxiliary blowing agent. The two most often used auxiliary blowing agents are CFC-11 and methylene chloride and these are used in the range of less than five percent to about 14 percent of the input chemicals depending upon the product manufactured, and which auxiliary agent is used. (As will be explained later, it takes fewer pounds of methylene chloride and a somewhat different formula to make the same type of product as CFC.)

Emissions of the auxiliary blowing agent are prompt; that is, essentially all of this agent disappears from the freshly made foam in a matter of hours or a few days. The foam can be thought of as a commodity that is manufactured by *passing the auxiliary blowing agent through it*. The blowing agent forms the cells, then leaves the foam almost completely before the foam leaves the factory.

Flexible urethane foams can be either molded into their ultimate shape, or produced in the form of a slabstock, a large, continuously-

made bun, which is sawed into pieces that have dimensions of several feet high and several feet wide, and lengths of 6 to over 200 feet. Foam molding is done either by the hot molding process, or by the newer high resiliency (HR) molding process, which uses warm molds.

Just as flexible urethane foams can be categorized as either slabstock or molded foams, they can also be categorized as water blown, CFC blown, or methylene chloride blown. Data to estimate the present distribution of these types are sketchy, but a very rough percentage breakdown based on the total pounds of foam appears in Table 2.

Table 2

FOAM PRODUCTION DISTRIBUTION

(percent)

<table>
<tr><th></th><th>Slabstock</th><th>Hot Molded</th><th>HR Molded</th><th>Total</th></tr>
<tr><td>Water blown</td><td>20</td><td colspan="2">20</td><td>40</td></tr>
<tr><td>CFC blown</td><td>27</td><td>7</td><td>8</td><td>42</td></tr>
<tr><td>Methylene chloride blown</td><td>18</td><td>0</td><td>0</td><td>18</td></tr>
<tr><td>Total</td><td>65</td><td colspan="2">35</td><td>100</td></tr>
</table>

SOURCE: Estimates from marketing data from the following: Mobay Chemical Company (see Upjohn, 1977b); Mobay (1978); Allied Chemical Company, Statement to EPA, October 25-27, 1977; Olin Chemicals Group, private communication.

The growth of output from the flexible urethane foam industry between now and 1990 is variously estimated by industry sources to be between 3 and 8 percent per year. Various forces acting on the molded foam portion of the market make projections of the CFC use somewhat less certain, but in general the same growth rates apply. Driving this growth in flexible foam markets is the expectation of greater than 5 percent growth in furniture and bedding markets, over 4 percent in the transportation market, and over 10 percent for carpet underlay and packaging, which are both relatively small uses. Emissions of CFC from the manufacture of flexible foams were about 13 percent of total estimated CFC emissions in 1976, and we project them to be about the same

fraction in 1990. Consequently, this product area deserves attention in the study of ways to reduce CFC emissions.

This report begins by examining historical data on foam production, and projections into the near future. Then these data are used to estimate the historical and projected emissions of CFC that are likely in the absence of any actions to modify them. Two technical methods of reducing the emissions are then examined in some detail, and the emissions reduction potential of each is estimated, as are the costs involved. Demand schedules are then estimated, based upon these cost and emissions reduction data. Finally, estimates are made of the emissions reduction and costs to firms of imposing the using of the technical options to reduce CFC emissions, and also of prompting their use by raising CFC prices.

II. SOME FACTS ABOUT THE FOAM INDUSTRY

Information about the structure of the industry relies mostly upon chemical supplier estimates and upon the response to confidential questionnaires that were sent to foam manufacturers by the Society for the Plastics Industry in cooperation with this study. Because of the relatively limited number of responses to the questionnaire, our characterizations must be viewed as qualitative. There are sufficient differences between molded foam and slabstock that it is worthwhile to describe these separately.

SLABSTOCK FOAM

Slabstock foam is manufactured in a foam tunnel. The various ingredients, including the blowing agent, are individually pumped as liquids to a traversing mixing head and discharge nozzle that is positioned at the entry to the tunnel. Once discharged, the mixed liquids lie on a conveyor belt that travels through the tunnel. The reaction of the various ingredients to form the urethane is exothermic, and thus the temperature of the mixture rises, and as it does so, the blowing agent is vaporized. It is this vaporization that forms the cells in the foam, and that causes the liquid mixture to rise until it is about four feet high. As the forming "bun" travels through the tunnel, the vaporized blowing agent is emitted from it, along with a variety of other gases that include unreacted TDI (toluene diisocyanate), one of the raw materials. Since the TDI concentration must be kept low because of its toxicity, the tunnel contains a ventilation system that sweeps these emitted gases, together with substantial quantities of excess air, out of the tunnel, and out of the plant, where they are discharged to the atmosphere in diluted form. The tunnel itself may vary in length from perhaps 50 to 100 feet, and the conveyor is designed to travel at a speed such that the slabstock has sufficiently "cured" to be sawed into pieces for warehousing after it has reached a point that is typically over 100 feet from the discharge nozzle. The sawed pieces, varying in length from perhaps 6 feet to 200 feet, are then warehoused.

There are about 50 companies that manufacture flexible slabstock. Roughly one-third of these are large companies, some of which have multiple plants spread over the U.S. These large companies each have an annual production volume in the range of 20 to 100 million pounds of foam a year, which would imply that on average they each consume in the range of 600,000 to three million pounds of CFC per year.

About 15 percent of the companies fall into the range of 10 to 20 million pounds of foam production annually, which would imply roughly 300,000 to 600,000 pounds of annual CFC use. The remaining companies are smaller, manufacturing less than 20 million pounds of foam per year. While foam plants may differ in size by a factor of 10 from the largest to the smallest, large foam companies tend to be multiplant companies, with each plant being located close to a market. A large company might have half a dozen plants across the country.

In terms of foam plants, we estimate that there are about 10 plants that are large enough to consume about one million pounds of CFC per year. One or two of these consume two or more times this amount. There are 30 to 60 plants that have an average consumption of 200,000 to 250,000 lbs of CFC per year, but which range up to a few in the region of 500,000 lbs of CFC. Then there are another 30 to 60 plants that use 100,000 to 200,000 pounds of CFC per year.

Slabstock foam is a low-value, low-density product, and foamers lose their competitive edge because of transport costs if located too far from their markets. This causes foamers to locate in the midst of their markets, which are predominantly furniture, bedding, and carpet underlay. There is a large concentration of furniture manufacturers in the Southeastern U.S., and many foam plants are located in North Carolina, Tennessee, Arkansas, and Mississippi. Flexible foam plants are also located in Southern California, another major furniture manufacturing center. Rhode Island, Indiana, New Jersey, Iowa, Massachusetts, Pennsylvania, Maryland, and Colorado all have slabstock foam plants, and it can be inferred that there is probably one near every major metropolitan area where there are furniture or bedding manufacturers. As might be expected given the importance of transport costs, little or no flexible foam is imported or exported.

Slabstock foam is not very capital intensive, and the technical know-how is readily available from the chemical suppliers. Thus, an individual with some key accounts in his control and some reasonable financing can enter the business fairly easily. But small foamers complain about the narrow margins they must live with, and just as a few accounts can cause an entry into the market, their loss could cause an exit. While large companies appear to be well established businesses and have been around for a long time, small companies may come and go. In fact, there are several companies whose sole business is the manufacture of foam production lines and whose customers are primarily new entrants into the foam production business.

Slabstock foam lines are all designed to produce a bun of similar cross section. Because of this, there is a great deal of similarity in the equipment used by large and small foamers, and the difference in plant output is controlled by the number of hours per day that the foam line is operated. A small foamer may only operate his line for one hour per day, possibly even skipping one or more days per week. A large foamer may operate for a full eight hour shift or longer. Consequently, foam equipment is being operated on the average at less than one-third of its capacity. Among the factors that might limit plant output are limited local market size, warehousing and storage space constraints, and transportation costs.

The industry does not appear very capital intensive, requiring about half a million dollars to set up the equipment for a small foam plant. The chemicals that are fed to the foam line frequently flow at the rate of about $500 worth per minute, implying that in 1000 minutes (17 hours) of operation, more value in raw materials will pass through the plant than was involved in setting it up. Larger plants often require much more investment because they are vertically integrated so as to process the slabstock into finished shapes for their customers. Our survey indicated that large firms have individual investments in slabstock plants that typically range from 10 to 15 million dollars, with the investment in each of their plants ranging from 2 to 4 million dollars. These same firms have annual sales of 25 to 75 million dollars. The ratio of capital inputs to total

production costs seems to run about one to two percent, which is far lower than most manufacturing operations.

Operation of the foam line generally requires about six people. In small plants where the line operates for only a few hours a day, these people are used in warehousing activities when they are not actually running the line. However, the bun product must be cut and trimmed to its final shape before use, and the cutting and trimming operations involve a great deal of hand work. Large multi-plant companies, characterized by annual sales in the range of $25 million to $75 million and CFC consumption of one million pounds or more, seem to have about 19 employees per million dollars of sales; i.e., a company with annual sales of $52 million would have 1000 employees connected with foam operations in 3 to 5 plants. In these plants, labor represents about 13 percent of the manufacturing cost. The foam output appears to sell for 50 cents to one dollar per pound, implying that, on average, there are 10 to 19 employees per million pounds of output.

Foam plants that are involved only in slabstock production, without cutting or trimming operations, may have substantially fewer employees. But since the cutting, trimming, and fabricating operations are an essential part of the conversion of the slabstock into a finished and salable product, we must presume that the people involved in these operations are simply on someone else's payroll, such as the furniture manufacturer. In assessing the employment related to slabstock foam, it would be shortsighted to overlook this. Total foam-related employment might be 13,000-25,000 people.

The output of the slabstock industry is closely related to the output of the furniture, beddings, and carpet industries. Originally, materials other than foam were used in furniture cushioning, but these have been largely replaced by foam. Bedding is made both with and without foam, but the desirable characteristics of foam probably mean that penetration of this market will increase. Similarly, the superior quality of foam carpet underlay probably means that penetration will also increase in that market, in a continuation of the historic trend to greater saturation.

CFC use represents only a small part of the final product price, and therefore, changes in CFC prices might have only a small effect on the final consumer. For example, in the softest foam usually used in furniture, the CFC presently accounts for about 13 percent of the raw materials cost. For a medium softness foam, the CFC represents only about 5 percent of material costs. According to furniture manufacturers, foam represents 10 to 15 percent of their manufacturing costs, which means that the CFC accounts at most for about 2 percent of the furniture manufacturing cost. Thus, changes in CFC price, even if passed through to the consumer at full markup, have little leverage on furniture prices.

Similarly, because the CFC content of carpet underlay is very low, the CFC leverage on its price would be very small.

For bedding, in which expenditures for foam might be the major component of bedding production costs, the situation is different. But even if mattresses used all supersoft foam (which has the highest CFC content), the CFC would only represent less than 13 percent of the foam cost, and leverage on the price of bedding would be small.

MOLDED FOAM

Molded foam plants do not resemble slabstock plants. The equipment is vastly different, with molds on an automated production line that runs through curing ovens, demolding stations, automatic release agent application, mold filling, product crushing, and wire filling operations. The entire line might be computer controlled in order to achieve high production levels and extremely accurate product quality control. We do not have industry-wide estimates of capital costs in typical large molded foam plants, due to limited responses to our questionnaire. But the responses received indicate that the investment and employment characteristics of large molded foam companies may not be too different from their slabstock counterparts having a comparable dollar volume of production. This may result in part from the fact that molded parts require much less hand work than the fabrication of slabstock, and the fact that the value per pound of molded foam output is about two or more times greater than that of slabstock.

The major consumer of molded urethane foam is the automotive industry, and this fact dominates the economic characteristics of this

sector of the foam industry. There are less than 20 companies involved (one source estimates 16), of which half make between 10 and 100 million pounds of foam per year. The balance consists of smaller plants, averaging perhaps 5 million pounds per year of output.

Whereas large slabstock companies usually have multiple plants, the same is not true for the molded foam companies, primarily because a major portion of their output is destined for a small group of customers in a relatively concentrated location--the automotive industry. Also the molding process lends itself to automation, and thus some plants are huge. The large size of a few of these plants means that they are also large single point sources of emissions, with several plants emitting between one and four million pounds of CFC per year.

Molded foam plants are found close to automotive assembly plants, with most of the molded foam being made in Ohio, Indiana, Michigan, California, and New England.

The output of the molded foam industry is directly related to the output of the automobile industry, and changes in automobile production can be expected to relate almost exactly to changes in molded foam production.

Molded auto seat bottoms are water-blown because of their stiffer character, and thus do not use any auxiliary blowing agents. The seat backs generally use CFC. According to foam molders, the HR process uses about 25 percent less CFC per pound than the older hot molded process. In either case, the CFC is a minor constituent of the material costs. Because the end product is generally an automobile, it is difficult to envisage any noticeable effect on final product retail prices that could result from changes in the price of the CFC used to make the seat backs.

Entry and exit from this market is rare, except perhaps for very small specialty molders. Recent conversions from hot molding to high resiliency (HR) molding processes have increased production capacity, and a crude estimate of the unused production capacity of the molded foam industry is about one third the level of current production.

III. HISTORICAL AND PROJECTED FLEXIBLE FOAM PRODUCTION

To provide context for the projections of flexible foam production, we first examine historical data. Table 3 lists these data, with several industry projections. The diversity in the historical figures demonstrates that there is no generally agreed upon source for these data. Each source differes from every other source, and while the industry totals are the values that are most in agreement, there are wide differences of either opinion or definition regarding consumption for each market segment. There are a number of reasonable explanations for this. Those who have made the estimates are predominantly suppliers of raw materials to the foam blowers. Because the foam blowers are their primary customers, their appraisal of the size of the total foam market is probably very good.

Moving past the primary customer to the customers of the foam blower involves much more uncertainty for a variety of reasons. For example, a particular foam blower might sell 90 percent of his output to the furniture industry, and 10 percent to the bedding industry (a hypothetical example). His raw material suppliers might simply list his total estimated output under the furniture category. Or the output of a foam blower might be sold to a company that makes both furniture and bedding, in proportions that are unknown to the foam blower, and, in turn, to the raw material supplier who makes the estimate.

Suppliers of raw materials are probably much more aware of the size of the total market, and the agreement on the aggregated production figures is much better than on the market sections. From these data, and the projections, we have synthesized the information presented in Table 4 as representative of the likely past production of flexible foams, and of the reasonable range of production to 1990. This range represents average annual growth rates of 3 to 8 percent. These rates reflect the range of rates frequently quoted in conversation

Table 3

FLEXIBLE URETHANE FOAM PRODUCTION DATA

(In million pounds)

Year	Reference	Bedding	Furniture	Packaging	Textiles	Trans-portation	Other	Prime Carpet	Total	Rebond Carpet	Scrap
Historical Production											
1960	a	6	48	3	3	25	1	---	86		9
1965	a	23	90	3	22	75	10	4	227		23
1970	a	72	226	11	66	189	30	27	621		52
	b								615		
1971	b								650		
1972	a	82	250	12	36	275	35	30	720		60
	b	110	353	7	15	244	7	74	810		
1973	g	115	370	18	32	364	27	32	958		
1974	c	← 440 →				340	152		932	175	
	g	132	386	18	31	375	27	32	1001		
1975	a (est.)	108	310	17	52	435	50	53	1025		100
	b	142	447	10	21	320	11	93	1044		
	c	← 465 →				285	165		915	140	
	d,g	136.4	352.0	19.8	26.4	341.0	17.6	30.8	924.0		
1976	b	153	482	11	23	345	12	100	1126		
	c	← 520 →				360	190		1070		
	e	116	410	24	25	340	85	100	1100		
	h	175	476	19	14	344	22	136	1186		
1977	b	160	479	12	25	344	13	105	1138		
	e	130	458	27	27	385	91	109	1437		210
	h	184	480	25	30	360	20	150	1249		
Projected Production											
1980	b	207	710	15	32	512	16	135	1627		
	e	145	530	38	30	425	115	146	1429		
	d,g	175	670	50	60	440	50	110	1555		
1982	e	172	535	34	27	420	105	160	1696		243
	e	190	587	43	32	531	116	175	1942		268
	e	227	654	54	35	552	128	192	2137		295

SOURCES:

[a]Bedoit (1974).

[b]Mobay Chemical Company (see Upjohn, 1977b).

[c]Upjohn (1977a).

[d]Allied (1977).

[e]Olin Chemical Group, private communication (1977).

[f]U.S. Department of Commerce.

[g]Modern Plastics (1978).

[h]Mobay Chemical Company (1977).

about the future with knowledgeable industry sources, and the dispersion of the estimates in 1990 simply reflects the various views of those making them.

The above discussion concerns projections of total foam production. The same practice could be used to project the foam production for each of the foam consuming market sectors. However, as was demonstrated in Table 3, the very great differences among the estimators, both for historical data and projections, suggest that the exercise would not be useful, and would simply lead to substantially wider dispersion in the 1990 sector estimates than is already shown in Table 4 for total foam production.

Table 4

ESTIMATED HISTORICAL AND PROJECTED FUTURE FLEXIBLE URETHANE FOAM PRODUCTION

(millions of pounds)

Year	Production
1960	86
1965	241
1966	307
1967	356
1968	480
1969	520
1970	618
1971	655
1972	746
1973	955
1974	979
1975	974
1976	1121
1977	1275
1980	1420-1690
1982	1696-2137
1990	1960-3240

SOURCE: Bedoit (1974); Mobay Chemical Company (see Upjohn, 1977b); and Mobay (1978); Upjohn (1975, 1976, and 1977); Allied Chemical Company, Statement to EPA, October 27-27, 1977; Olin Chemical Group, private communication.

IV. HISTORICAL AND PROJECTED CFC USE AND EMISSIONS

Estimating the amount of CFC that has been used to make flexible foams, and that will be used in the future, is complicated because there are many types of foams that are made in a variety of ways, and disaggregate data do not exist. Whereas there is a reasonable amount of data available on the historical production of flexible foams, data concerning the amount of CFC used to produce these foams are less readily available. Part of the reason for this is that the blowing agent is a minor expense in contrast to the other chemical raw materials, usually representing less than 10 percent of the raw materials cost. But another reason is that CFC is supplied by several producers, and for them to estimate the market consumption of CFC requires that they not only understand the position of the other makers of CFC, but also the markets for foams blown without auxiliary blowing agents, and those blown with methylene chloride.

Available estimates are of two types. The first is a direct estimate of CFC use in the manufacture of flexible foams. This type of estimate is available from producers of blowing agents. The second is based upon an estimate of the fraction of total foam production that was blown with CFC, and the unit CFC consumption of this fraction.

Direct Estimates

Table 5 lists direct estimates of CFC use in flexible polyurethanes for 1970, 1974, and 1976, as submitted to EPA by DuPont [4].

A second direct estimate was provided by another manufacturer of blowing agents, and resulted from a proprietary survey of flexible foam manufacturers. The survey estimated that 26 million pounds of CFC were consumed in the manufacture of slabstock *alone* in 1976. Since we know that CFC is also used in molded foam, there is clearly a disparity between the value shown in Table 2 and this survey value.*

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*Both the direct and indirect estimates of CFC use may be clouded by the fact that CFC and methylene chloride may be used as a blend. It is not known whether these blends have been counted as though they were pure CFC, pure methylene chloride, or whether the appropriate adjustments were made.

Table 5

ESTIMATED USAGE OF CFC BLOWING AGENTS FOR FLEXIBLE POLYURETHANE, MILLIONS OF POUNDS

1970	16.8
1973	Not available
1974	26.7
1975	Not available
1976	26.9

SOURCE: E. I. Du Pont de Nemours and Company (1978a)

The survey value cannot be used directly to draw an implication about the total use of CFC for all flexible foams, because molded foams which comprise the remaining portion of the production do not appear to use CFC in the same proportions as slabstock.

Since the above data are the only published (and unpublished) direct estimates of CFC use in flexible foams for the years 1970, 1974, and 1976, the construction of a historical series of emissions estimates must rely on other techniques. We already have reasonably good estimates of the historical foam production, and with an idea of the average unit consumption of CFC in the foam, the emissions estimates could be made. The data presented above can be used to estimate average unit CFC consumption, and similar estimates are available from previous work in the form of indirect estimates of CFC emissions.

Indirect Estimates

Indirect estimates are taken from the MRI and BDC reports, which are in turn based upon data from *Modern Plastics,* Mobay Chemical, and the study made by ADL. The elements of the estimates are:

a. total foam production

b. fraction of total production that used CFC

c. unit consumption of CFC by the CFC-blown foams.

Table 6 lists the factors and the computations that were carried out in the source reports. From the factors, an estimate of the average unit CFC consumption can be made by multiplying b and c above. The accuracy of the factor will be contingent upon the accuracy of the estimates of both the fraction of total production that uses CFC, and the unit consumption of CFC by the CFC-using foams. Some idea of the probable subjectiveness of these values is conveyed by the fact that ADL estimated that 55 percent of flexible foams used CFC, and MRI estimated that less than 1/3 of them used CFC, for time periods in which there were similar types and amounts of foam produced. There is also a similar difference in opinion on the average consumption of CFC by the CFC using foams. These differences are partially offsetting, and when the factors are multiplied the ADL estimate of the average CFC content of *total foam* output is 3.85 percent, and the MRI estimate is about 3.17 percent.

Combined Estimates

The direct and indirect estimates are summarized in Table 7. The lack of consistency of the data in Table 7 is disappointing, but the data must be used as the basis for estimating past and future CFC emissions from flexible foams.

Projected CFC Consumption Rates

We begin with the assumption that the 1976 survey results are a reasonable estimate of average CFC consumption in slabstock. For molded foam we have no comparable figures, and consequently, we shall use the indirect estimate made by MRI and presented in Table 7. From these two estimates, and the estimated division between slabstock and molded foam of 65 percent and 35 percent, the combined average CFC content of all foam is 2.92 percent. This estimate is lower than suggested by the ADL and MRI estimates and higher than implied

Table 6

AGGREGATE CFC-11 USE BY FLEXIBLE URETHANE FOAMS

Type of Foam	Data Year	Total Foam Output (million pounds)	Percent Using CFC	Estimated CFC-Blown Foam (million pounds)	CFC as Percent of Foam Weight	Estimated CFC Usage (million pounds)
All flexible foam	ADL, 1973	960	55%	530	7.0%	35.4
Flexible slabstock	MRI,[a] 1975	660	33	218	10.4	22.8
	MRI,[b] 1975	775	33	256	10.4	26.2
Flexible molded foam[c]	MRI,[a] 1975	264	30	79	8.3	7.0
	MRI,[b] 1975	269	30	82	8.3	7.3

SOURCES: ADL, p. LV-79, and MRI-III, p. IV-38 to 39.

[a]Based on *Modern Plastics* data.

[b]Based on Mobay data.

[c]Numbers for molded shapes do not compute exactly, because of apparent computational errors in the MRI tables.

by the DuPont data. In the projections to follow, 3 percent will be used as the estimate for all flexible foams, 3.2 percent will be used for slabstock, and 2.5 percent will be used for molded foam.* Where indicated, sensitivity analyses will illustrate the effects of uncertainty in these values.

Table 7

ESTIMATES OF AVERAGE CFC USE IN FLEXIBLE FOAMS

Year	Direct Estimates		
	Total CFC use, millions of pounds[a]	Total Foam Production millions of pounds[b]	Average use, % CFC
1970	16.8	618	2.69
1974	26.7	979	2.72
1976	26.9	1121	2.45
1976	26.0[c]	825[c]	3.15[c]

Year	Indirect Estimates			
	Source	Slabstock, % CFC	Molded Foams, % CFC	All Foams, % CFC
1973	ADL	-	-	3.85
1975	MRI	3.43	2.49	-

[a]E.I.DuPont de Nemours and Company (1978a), except last entry from proprietary survey.

[b]Values from Table 4.

[c]Estimates refer to slabstock foam only.

Table 4 can be used as the basis for projecting CFC use and emissions by making assumptions about the CFC consumption per unit of foam. We have already seen that the historical data on this is subject to some uncertainty, but compounding this is the fact that there are

*Note that these calculations have derived average values for *all flexible foams,* and include water-blown foams and those using methylene chloride as an auxiliary blowing agent.

some trends underway that will affect these ratios. These trends will be treated in some detail later in this document, but in summary, they consist of actions affecting molded automobile seats. These seats are changing size and shape as a result of car downsizing, their density is being lowered, and most important, the manufacturing process is rather rapidly changing from hot molding to the HR process. The net effect of these changes is that average CFC consumption in molded foam destined for car seats could be reduced eventually to about 2.0 percent from the presently estimated 2.5 percent. We do not know the rate of these changes, and how their interrelationships affect the total use of CFC in molded foam seats. Consequently, we have assumed simply that the eventual reduction of average CFC use to about 2 percent will occur by 1990. Using these assumptions and the foam production estimates of Table 4, we estimate historical and projected CFC use and emissions, and list these estimates in Table 8.

Table 8

PROJECTIONS OF CFC USE IN FLEXIBLE FOAMS,
MILLIONS OF POUNDS

Year	Low Estimate	High Estimate
1980	43	51
1982	50	63
1984	51	70
1986	52	76
1988	53	83
1990	54	89

SOURCE: Projections in Table 4, average CFC content developed in text, and an assumed ratio of 65% slabstock and 35% molded foam.

V. METHODS OF REDUCING CFC EMISSIONS

This section presents discussion on the known methods of reducing CFC emissions. The technical characteristics of each emissions reduction method are explored, including those characteristics that bear upon the economics of the method. A formal treatment of the economics of emissions reduction is reserved for a later section that uses the data discussed here.

CFC SUBSTITUTION

Low-density flexible urethane slabstock requires the use of an auxiliary blowing agent. CFC is the predominant agent used, but methylene chloride and CFC/methylene chloride blends are also used. Methylene chloride is not an exact substitute for CFC, and therefore, a discussion of substitution possibilities must focus on the differences between the two blowing agents in terms of raw materials used, processing control, quality of product, and costs, and other differences perceived by foam blowers. Industry sources generally agree that about 60 percent of the flexible foam that uses auxiliary blowing agents is blown with CFC, and that 40 percent is blown with methylene chloride. Methylene chloride owes its competitive position to its appealing economics. Two factors make it desirable. First, since it has a lower molecular weight than CFC-11, it takes fewer pounds of it to generate the same volume of gas, which foams the urethane. Second, it has historically cost less per pound than the CFC. The theoretical advantages of these two factors are compelling; however, in practice they are somewhat reduced. Methylene chloride has a higher boiling point than the CFC, and the amount of heat required to vaporize it is greater than for the CFC. This causes a somewhat later foaming action in the foam tunnel, and for some formulations changes in other precursor chemicals are required. These other changes--both in the type and quantity of ingredients--together with the lower blowing agent costs, result in estimated net savings of four to seven percent of the input raw materials costs. Since the foam industry is highly competitive, the apparent advantage offered by using

methylene chloride is an attractive one, and we found foamers who told us that they relied on the use of this blowing agent to give them a competitive edge, to extend their marketing area, and to increase their profits.

With methylene chloride being offered as virtually a complete replacement for CFC that would reduce foam material costs, one must question why there has not been a wholesale conversion to its use, and why it is that its use coexists with CFC in large marketing areas under competitive conditions. The reasons are rooted in technological questions, economic uncertainties, and safety aspects. Each of these has been addressed at length by the vendors of methylene chloride, but either real or imagined problems with its use have impeded switching from CFC, and the economic margin between foamers who use one or the other appears insufficient to force the issues. We will look at each of these subjects, since they describe what a foamer faces when making a choice of auxiliary blowing agent for use on a slabstock line.

Early foaming technology limited the use of methylene chloride to foam formulations containing relatively modest amounts of auxiliary blowing agent, primarily because amine catalysts capable of working with higher concentrations were not available. In addition, foams that were blown with methylene chloride tended to discolor, and even though the technical characteristics of the product were satisfactory, users preferred the color of CFC blown foam. This problem of discoloration has been largely solved by the development of a special grade of methylene chloride for foam blowing which eliminates the problem, and, consequently, discoloration no longer appears to be a real issue. With regard to the concentrations of methylene chloride that can be used, there appears to still be a spirited debate. Dow Chemical has worked extensively on the subject of foam chemistry, and advertises that catalysts and surfactants are available to allow high concentrations of methylene chloride to be used, even up to the super soft grades. Supporting this position, we found at least one large foamer who supplies the furniture industry (with soft foam) who claimed to use methylene chloride alone to manufacture 95 percent of his output. The remaining 5 percent were said to be small production items on which the R&D

necessary to effect conversion to methylene chloride exceeded the relatively modest returns that might be had. But we also found widespread disagreement with the statement that methylene chloride can be used in super soft foams, even from some companies who presently use it in other foam grades. Whether or not the question has a clear-cut technological answer is unresolved. Suffice it to say that there is spirited disagreement about the adequacy of the technology, and this affects the willingness of some foamers to use methylene chloride.

While formulations using methylene chloride can be shown to have a 4 to 7 percent lower material cost, foamers are quick to point out that this is only one part of the picture, because it assumes that equal amounts of salable product are made using each blowing agent. Closer examination of this question shows that methylene chloride foam formulations are more sensitive to the control of the catalysts than are CFC foam formulations. The catalyst concentration can be varied over a wider range when using CFC while still producing a high quality foam than it can with methylene chloride. Consequently, the use of methylene chloride may increase the level of rejected product (or scrap) in a slabstock plant. Moreover, as methylene chloride concentrations increase, this phenomenon becomes more pronounced. As a result, the foam line operator must exercise more attention and skill when using methylene chloride than when using CFC in order to produce equivalent amounts of foam of acceptable quality.

Our interviews with slabstock foamers produced a surprising variety of opinions on this question, and production practices that conformed to these opinions. At one extreme, we found a number of foamers who contended that the use of methylene chloride posed no problems at all, and who felt that their scrap rate was no different from anyone else's. These foamers also described the greater sensitivity of the methylene chloride formulations by admitting that "the gate was narrower than the gate of CFC formulations, but they are both wide enough to drive a truck through." They also generally felt that making super soft foams with methylene chloride was not a great problem, and at least one of them was installing larger capacity methylene

chloride measuring equipment so that he could make softer foams. Generally, but not always, these opinions were voiced by small to medium sized foamers.

At the other extreme, several large and very large foamers who use both CFC and methylene chloride, alleged that they used methylene chloride whenever it was the economically favored blowing agent, and that there simply were formulations where the CFC was, on balance, less expensive to use. Part of this reasoning had to do with the costs of the other ingredients in the formulation, and part had to do with the scrap rate. When questioned about scrap, the general conclusion of these large foamers was that *in general* one can expect a higher scrap rate when using methylene chloride. Confronting these foamers with the opposite opinions of others brought the response that some foamers have lower internal quality standards than others, and that some foam users also have lower standards. To the extent that neither a foamer nor his customer either perceives or cares about the fact that some of the foam produced is of lesser quality than the rest, the question of scrap rate becomes moot.

But there clearly are customers who do discriminate, and who do demand high standards. In these cases, the foamers are very sensitive to the quality of their output. As an example of this sensitivity, we spoke to one foamer who has a number of plants, and who attempts to maximize his use of methylene chloride. This foamer has found that in those plants where he has strong technical support he can achieve higher levels of methylene chloride use than he can in his other plants without the scrap rate becoming excessive. Clearly, if a foamer is to contemplate switching from CFC to methylene chloride, he must make some assumptions about how his scrap rate will change. There are no data on this subject, but one might easily surmise that there are careful operations and some types of products for which the scrap rate is no different, and also that there are more casual operations and more demanding products where changes in the scrap rate may have cancelled any apparent savings in raw materials. Whatever the actual history may be, there are foamers whose opinion is that the case for lower *overall* costs is far from clear. They believe that the theoretical

savings of 4 to 7 percent are on the high side, and that there actually could be a net loss in some cases.

In this connection, it could be expected that those small foamers whose strength lies in marketing rather than in technical expertise. might be biased towards the use of CFC based technology. These foamers probably would be the least equipped to cope with the demands of a more exacting technology, the misuse of which can result in a higher scrap rate.

A second potential economic factor concerns the additional capital investment required when methylene chloride is used. This results mostly from the lower TLV* of methylene chloride, maintenance of which requires more ventilation than for the higher TLV of the CFC. However, most foam plants are already well ventilated to control TDI concentrations, and ventilation is relatively inexpensive to add. Consequently, these capital additions, if required, are probably never large for any well designed plant. We were advised by some foamers that methylene chloride vapors in the foam plant cause additional corrosion, particularly when ingested into the plant heating system. Checking this information with those using methylene chloride failed to uncover any major problems of this type. Indeed, one foamer who has used both blowing agents stated that CFC also caused corrosion in heating systems. Here again, differences in cost appear modest.

What may be of more consequence in some particular applications may be additional energy costs. Usually the curing and warehousing areas of the plant are ventilated by the exhaust fans in the foam tunnel. Air sweeps through the warehouse from outside the plant, into the tunnel, and through the exhaust system to the outside. There may be some cases where the warehousing and curing areas are physically separated from the foam tunnel, so that a separate exhaust system is required for these areas. This results in a total air exhaust that is larger than for an integral plant, and larger than for a CFC using plant, because

*TLV stands for Threshold Limit Value, and is the maximum legal average concentration of a substance that a worker can be exposed to under Occupational Safety and Health Administration (OSHA) regulations.

of the lower TLV of the methylene chloride, and because methylene chloride emissions from fresh foam occur later than when using CFC. In cold climates, the air must be heated, and the extra energy cost of doing this would be an offsetting factor to the lower material costs. It is not known how many foamers would be in this situation, but the number is probably small.

When technological and economic hurdles have been crossed, there is the question of the relative safety of the two blowing agents. CFC has several enviable properties in this regard. First, it is an extremely stable compound--stable enough that it has resulted in suspected problems in the upper atmosphere. Partially because of this stability, it has a TLV of 1000 ppm, which is the highest value assigned to gases. Supplementing the high TLV is the fact that CFC are odorless. Those working in a foam plant using CFC detect no odors, and the high TLV is assurance to both management and labor that the use of CFC is safe, as presently practiced.

In contrast, the TLV of methylene chloride is presently 500 ppm, as set by the Occupational Safety and Health Administration (OSHA). The American Conference of Governmental Industrial Hygienists has recommended a reduction to 200 ppm, the same value recommended by Dow, and established by the California State OSHA. Methylene chloride also has a distinctive odor, which is detectable at about 300 ppm. Since the TLV is a time weighted average, even though a TLV of 200 ppm may be enforced, the concentrations may well exceed 300 ppm at times, and the odor will be noticed.

Some CFC using foamers expressed alarm at this, since they felt that their workers would complain and object to the change from the odorless CFC. However, there are also positive aspects to the odor, in that if it can be detected, it may be a warning that there may be a ventilation system malfunction that would go undetected with an odorless gas. On the surface, there should be no problem with foamers contending with the different TLV. While the CFC appears admittedly more benign, the effluent gases from the foaming operation contain TDI, which has a TLV of only 0.02 ppm. The TDI vapors exist regardless of

the auxiliary blowing agent used, and foamers adequately handle them despite the extremely low TLV. Further, a large amount of foam is already blown with methylene chloride without serious problems in handling the effluent gases.

Despite this, heated discussions about safety are almost guaranteed to result whenever the subject of methylene chloride is raised with CFC using foamers. To develop information about methylene chloride, Dow and others have conducted large (and expensive) studies of the health effects of the chemical on animals and on workers exposed to the material over long periods of time. The published results of these studies appear to corroborate what the producers of methylene chloride have alleged; i.e., that it is a safe material when handled with regard for its properties. On the other hand, those who are supporters of CFC state that the results of a study by the manufacturers of methylene chloride must be expected to support their claims, and that there are "other factors" that must be considered, or that "the whole story" was not told. Little evidence is available in the way of systematic studies to support this position, but if a foamer believes that a substance is toxic, he won't use it regardless of study results to the contrary. If he suspects that his foam line operator will be subject to some slight narcosis from the vapors, and that this will render him less attentive, so that some bad quality foam will be made, he can easily believe that any expected cost savings will be wiped out.

Foamers who convert from CFC to methylene chloride essentially trade one type of emission for another. In a social and political climate that is increasingly sensitive to environmental issues, a foamer may very likely consider that converting to methylene chloride from CFC in order to reduce CFC emissions may provide only a temporary respite from emission regulation, in that at some later date, methylene chloride emissions may also be restricted.

Given the above perceptions about methylene chloride, one finds that the present major use of this blowing agent is either by itself in medium softness foams, or as blends with CFC where a desirable combination of low material costs and wide operating latitude exists. Some foamers have pioneered its use in supersoft foams, together with

assistance from suppliers of precursor chemicals and methylene chloride. One also finds that for the most part, foamers using the two auxiliary blowing agents compete in the same markets. As a result, it is easy to conclude that the overall differences between using the two blowing agents are insufficient to cause one of them to predominate at the present.

The above discussion presupposes certain attributes of the foam produced by the two blowing agents, namely that the quality is equivalent and that the price is the same. We found that there were foamers who claimed to be able to tell the difference between CFC blown and methylene chloride blown foam by handling it. Our interviews with furniture manufacturers convinced us that some were unable to see any difference. Some furniture companies buy both types of foam, but were completely unaware of any differences between them, and in fact, were surprised to learn that there was more than one way to make it. It would seem that the primary consumers of most grades of flexible slabstock and their ultimate customers would observe little or no changes in either price or quality if foamers were to switch to greater use of methylene chloride.

Our present perceptions are that there is almost a standoff between the two auxiliary blowing agents. If there is a movement towards one or the other, it is slow, and relatively unimportant from the standpoint of near term CFC emissions reduction. But the leverage on the material cost savings is very great, and an increase of the *price differential* between the two blowing agents could be expected to initiate shifts to the use of methylene chloride.

The actual conversion process cannot be done instantly because of the required reformulation of the foam and some "fine tuning" of the new formulas on the foam line itself. Also the operators need to be schooled in the differences that they can expect when using the new formulations. In practice, a trial formulation is designed to match the foam that is being made. This formula is tested on the line, and the product is evaluated. Adjustments are made as necessary until the formula produces the desired product. For large foamers with their own technical

staffs, it has been suggested that the bulk of this work would be done by the foamer himself. For foamers without technical staffs, outside help in the form of technical teams from the material suppliers would be relied upon.

From the viewpoint of reducing CFC emissions, the substitution of methylene chloride as an auxiliary blowing agent is 100 percent efficient, in that substituting methylene chloride completely eliminates the CFC. The question of interest then becomes the degree to which foamers could convert, if they were motivated to do so. Despite the apparent availability of the technology for even the super soft foams, there are special cases where attempting to use methylene chloride would either be difficult, uneconomic, or where it would alter conditions so that some foamers might go out of business. Taking these in order, substitution might be difficult for some types of foam. We have not specifically identified the characteristics or amounts of these, but we were advised by foamers who presently use methylene chloride that there are certain foams with which they have great difficulty achieving the required quality levels when using methylene chloride. This is not a case of excessive scrap rate on an otherwise successful formulation, but rather a case where it is apparently difficult to match the required characteristics of the CFC blown foam.

A certain number of cases may be initially uneconomic. The design of formulations that use methylene chloride for the commonly produced foams has been done by the chemical suppliers through the investment of R & D funds. They have expended this effort, and made the investment in the hopes of realizing a return through the sale of the methylene chloride and precursor chemicals that are the formulation ingredients. There are many types of foam that are blown in relatively small quantities, and for specialty purposes, where the investment required to develop alternative formulations has not been made and may not appear economically attractive. Foamers making these types of foam would be unable to switch, and also unable to pay for the R & D. This problem may only be a short-term problem since if CFC were either too expensive or unavailable, the development of

new specialty foams would be confined to those that could use methylene chloride. How long the intervening period might be is unknown.

The last case is one that has been previously raised, and concerns the increased sensitivity of the methylene chloride blown foams to the control of catalysts. The operation of the foam line with these formulations requires more care, and the penalty for not exercising it is a higher scrap rate. There is apparently a proportion of the foaming industry that is made up of foamers who may have one or more of the attributes of being small, marginally capable, or marginally economic operations. For these foamers who may understand very little about the control of their operation, the conversion to methylene chloride might bring disaster.

Assessing the effect of these three categories is difficult, since there are no data by which the estimates could be made. Subjectively, a group of industry knowledgeable individuals responding to our interim report under the SPI letterhead suggested that the above groups might collectively represent 25 percent of the CFC emissions. Accepting this estimate would indicate that a conversion to the use of methylene chloride could reduce present CFC emissions from flexible slabstock foamers by 75 percent.

A rough estimate of the amount of CFC used in the manufacture of flexible slabstock is about 30 million pounds in 1976. Substitution by methylene chloride in 75 percent of the slabstock would bring about a reduction in CFC emissions of 22.5 million pounds. Molded foam presently uses and emits about 11 million pounds of CFC, so total emissions could be reduced from about 39 million pounds to about 18.5 million pounds by switching to methylene chloride, or by about 55 percent.

A reduction in CFC emissions would be accompanied by an increase in methylene chloride emissions. As explained earlier, the replacement of one pound of CFC requires about 15 percent less than one pound of methylene chloride, so the increase in methylene chloride emissions would be about 16.5 million pounds.* Thus this substitution scenario would roughly halve the present CFC emissions and double the present

*Note that this is based upon the assumption of an equal scrap rate. Should the scrap rate be higher than with CFC, more production (and more methylene chloride) must be used to obtain the same output of foam.

methylene chloride emissions in the manufacture of flexible urethane foams.

Emissions reductions in 1990 would be proportionately the same under conditions where the present product mix of slabstock, hot molded, and HR molded foams is assumed. This is not likely to be the case, as we have discussed, due to the dynamic changes occurring in the manufacture of molded foams. We have assumed that the conversion to the HR process will be completed; then CFC emissions from molded foam plants will be reduced to about 80 percent of the present rate. The effect of this would be that total emissions from flexible urethane foam manufacture would be reduced by about 60 percent from the emissions that are projected in the previous sections.

The above discussion has concentrated on the substitution of methylene chloride for CFC in flexible slabstock, and a logical question is whether this substitution can also be made in molded foam. Both molded foamers and methylene chloride manufacturers have devoted some time and effort to this question, but with only qualified success. Apparently blends of up to 20 percent methylene chloride with CFC can be used fairly satisfactorily, but attempts to use greater substitution adversely affect the foam quality. For this reason, the potential of substituting methylene chloride is probably limited to 20 percent in molded foam. Little additional research is being done regarding methylene chloride, because an area of more promise is the development of soft molded foams that use no auxiliary blowing agents. Research on this appears that it will be fruitful, with the main problems being the maintenance of low densities. This is discussed at greater length in a later section.

CFC RECOVERY/RECYCLE

The principle behind CFC recovery and recycle is simple. Flexible urethane foams are prompt emitters, and the basic idea is to capture the CFC emissions during the period when the foam is under the manufacturer's control. The captured CFC would then be recycled back into the foaming process.

The basic technology of CFC recovery is fairly well known. Carbon beds are used in a cycle that alternates between adsorption and desorption. CFC-11

is a gas that is amenable to collection by carbon adsorption, and there are a reasonable number of industrial applications where the recycle and recovery of CFC-11 is economically practiced today. None of these applications include foam blowers, and the only presently known attempt to capture and recycle CFC on a foam line was made in 1968 by the General Tire and Rubber Company [6]. Little information survives from this test, but we were told that an insufficient amount of the CFC could be captured to make the process economical, and that the foam line operators were not enthusiastic about the additional equipment involved. Although there is no more recent experience with the technology as applied to flexible foam, there appears to be no technical reason why it would not work.

While not mentioned in reference to the trial, others have pointed out that while carbon adsorption works well with *pure* CFC, the gases collected from a foam line contain amines and TDI vapors. These vapors must be dealt with either by pretreating to remove them, or by designating a portion of the carbon bed specifically to adsorb them. In either case the presence of these vapors complicates the process somewhat and increases the capital cost of the equipment. Many foamers and their trade organizations doubt the potential of carbon adsorption, but two knowledgeable concerns believe that it merits investigation.*

The parameters that control the emission reduction potential are the collection efficiency and the adsorption-desorption efficiency. The overall efficiency of the recovery/recycle process is the product of these. Collection efficiency refers to the ability to collect the CFC vapors as they are emitted from the foam and the adsorption-desorption efficiency is a characteristic of the carbon beds themselves, and is controlled by the design and manufacture of the device.

In practice the manufacturer usually guarantees the adsorption-desorption efficiency of the carbon beds to be greater than 90 percent. In the 1968 test referred to above, the efficiency of the carbon beds was stated to be about 95 percent [7]. Because the efficiency of the

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*DuPont and Vic Manufacturing.

carbon beds is quite high and can be expected to be known with certainty, we can treat it as a known constant with a value close to unity for the purpose of making estimates for this study.

The overall efficiency of the recovery/recycle process then becomes a function of the collection efficiency. Estimating the collection efficiency of present day foam plants is difficult because the foam lines differ, the ventilation systems also differ, and because there are few measurements that have ever been made on the CFC content of the exhaust gases. The motivation behind all foam line exhaust systems is the reduction of TDI vapor concentration, because TDI has a TLV of 0.02. This extremely low TLV has resulted in foamers usually using large exhaust fans, with the general idea that it is far better to err on the safe side than to risk having toxic TDI vapors in the working place.

We do know that the 1968 test had collection efficiencies of about 33 percent. DuPont has made some recent measurements at three foam plants that yielded results of 53 percent, 33 percent and 9 percent respectively. We also know that a Japanese patent* on CFC recovery and recycle has been issued that claims a collection efficiency of 86 percent. For the purpose of evaluating the emissions reduction potential of recovery and recycle, we will examine a range of the combined collection and adsorption efficiencies from 30 to 80 percent.

This range has been selected because it encompasses the reported collection efficiency of the 1968 test on slabstock at the low end, and probably approaches what extensive collection modifications to slabstock lines could achieve on the high end. There is less experience with molded foams, but estimates made by MRI [8] indicate that 30 to 40 percent of the CFC emissions occur in the molding cycle and that perhaps 60 percent of the CFC are emitted during post-curing and crushing. Thus the 30 percent to 80 percent range is probably equally applicable to molded foam.

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*Patent Application 1976-242544, Japan Patent Agency.

Comparison of CFC Substitution and Recovery/Recycle

From a purely technical standpoint there is an interesting comparison between CFC substitution and CFC recovery/recycle. The maximum potential to reduce CFC emissions by using CFC substitution is limited by the present inability to use alternative blowing agents in molded foam and in about 25 percent of slabstock. Thus, absent any changes in these factors, the maximum emissions reduction potential appears to be about 56 percent in 1990.

CFC recovery and recycle can be used on both slabstock and molded foam lines, and would be equivalent to CFC substitution if collection/ adsorption efficiencies of 56 percent could be realized. Given that at least one actual plant measurement of 53 percent has been made, it seems reasonable to assume that recovery/recycle could be at least equivalent to CFC substitution in its emissions reduction potential.*

If emissions reductions greater than 56 percent were desired, one must estimate the potential for each of these methods. We have discussed some of the factors concerning CFC substitution, and for CFC recovery and recycle we can say that improved collection efficiency is the key. In this regard there have been a number of suggestions by industry representatives that suggest that relatively straightforward changes to the existing ventilation systems might provide such improvements. The limiting factor could be the degree to which all of the CFC is emitted while the foam is still under the influence of the existing ventilation system. For example, CFC emissions from slabstock might be fairly easy to collect while the slabstock is either in the foam tunnel, or even outside the tunnel but still on the conveyor system, if the tunnel were extended. But once off the conveyor, the foam is stacked in the warehouse to cure. The amount of emissions occurring in the warehouse is unknown, and collection of the CFC may be difficult because it is not very concentrated. This subject would clearly require more study before the ultimate potential of recovery/recycle could be assessed.

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*This is based, in part, on CFC substitution only being possible for 75 percent of the CFC blown slabstock. If this value should increase, increased collection/adsorption efficiencies would be required for the two methods to have equivalent emissions reductions.

CHANGES IN FOAM TECHNOLOGY

An ideal solution to the question of emissions of auxiliary blowing agents from flexible foam manufacture would be the development of foam technology that made these blowing agents unnecessary. The HR process for making molded foam is one approach to this. The HR foam process usually requires less auxiliary blowing agent to make a product than does the non-HR process. Further research into still greater reductions in CFC use is actively under way. Widespread conversion to HR foams is unlikely. They require substantially more material inputs, and these materials are more expensive than those used in conventional formulations. HR foams can be regarded as a specialty item that has found a particular niche in the economy. The lower CFC consumption of these foams is built into the estimates of CFC emissions made earlier. Present and anticipated efforts to further reduce CFC use in HR foam have also been built into the CFC emission projections, and thus are part of the "base case."

REDUCING FOAM OUTPUT

One last method of reducing CFC use and emissions is to reduce the output of flexible foam. The softest foams use the most CFC, and banning the manufacture of these grades of foam could effectively reduce emissions, albeit not without drastic effects on some businesses. No further analysis of this option was made.

VI. THE ECONOMICS OF EMISSIONS REDUCTION

In the previous section, we have identified two technical methods by which CFC use and emissions could be reduced while still preserving the availability of flexible urethane foam. One, CFC substitution, is already in partial use. We have suggested that while there appear to be cases where this use is based upon favorable economics, in general the picture is not crystal clear. The implied economic similarity of the use of CFC and methylene chloride is emphasized by the fact that there are markets where foams produced by both methods compete with each other. The second, CFC recovery and recycle, has an intrinsically strong appeal. Why purchase CFC, pass it through a foam formulation, enjoying only minutes or hours of its use, and then discharge it to the atmosphere in a form that could probably be reused for the same purpose? But this system is not in use on flexible foam lines anywhere, even though other industries have found that the idea is technically sound and have adopted the practice as a cost saving measure. This circumstance is evidence that flexible foamers do not believe that CFC recovery and recycle is economically viable for them at current CFC prices.

If CFC use and emissions are to be reduced through the use of control strategies such as the imposition of rules and regulation, it is important to understand what costs this will impose upon the industry. Similarly, if CFC emissions reductions are to be stimulated by economic incentives, an understanding of the economics of the technical means of reducing them is essential to the design of the incentives. This section will explore the economics of CFC substitution and of CFC recovery and recycle.

CFC SUBSTITUTION

We have previously noted that CFC substitution presently appears practical for about 75 percent of the flexible slabstock that currently uses CFC as an auxiliary blowing agent, and that it is not presently a commercial possibility for flexible molded foam. The discussion that follows will assume that these conditions are immutable. However, it should be realized that the limits of CFC substitution were established through discussions with industry that assumed present CFC prices. Should economic incentives be instituted to move foamers away from the use of

CFC, the picture might well change. For example, the 75 percent substitution limit on slabstock was partially based upon the premise that some formulations were not produced in sufficient volume to merit the R&D expenditures necessary to design substitute formulations. This judgment clearly requires assumptions about CFC prices, which, if increased, could be expected to alter the perceptions of whether R&D was economic. We do not have data with which to address this question, and consequently will assume that the limits of CFC emissions reduction through CFC substitution are fixed. This assumption biases the estimates of emissions reduction, which in actuality will be larger than estimated.

We begin by looking at slabstock since molded foam cannot substitute blowing agents. The CFC using slabstock industry, by the definition above, consists of 75 percent that can be converted to methylene chloride, and 25 percent that cannot. We also assume that the foamers who can use either blowing agent will substitute methylene chloride for CFC when the cost of using it is less. The following expression identifies the condition under which this will happen: *

$$(P_a A + P_m M)\alpha < (P_c C + P_m M)$$

or

$$[C(0.85P_a + 2.28)]\alpha < [C(P_c + 2.28)],$$

for a super soft formulation,

where:

P_c = CFC-11 price, \$/lb

C = CFC use per plant, pounds/year

P_a = methylene chloride price, = \$0.22/lb

A = methylene chloride use per plant, pounds/year

P_m = Price of non-blowing agent materials, \$/lb

M = Quantity of non-blowing agent materials, pounds/year

α = weighting factor (see text)

*As written, this expression assumes that P_m and M are identical for both CFC and methylene chloride formulations. This is not strictly true, and the equation has been written as shown in order to capture the differences in the weighting factor, α.

The above relationship is such that a foamer's decision about which blowing agent to use depends only on the relative prices of the two agents, and the value of the weighting factor, α. Since only 85 percent as many pounds of methylene chloride are required compared to CFC, and since the price of methylene chloride has always been less than that of CFC, the present relative equilibrium in the use of the two blowing agents can be ascribed to the weighting factor. Various perceptions affect the value of α. First, formulations that use methylene chloride must use adjusted amounts of catalysts and other ingredients that tend to be more costly than those used in CFC blown formulas. Second, the scrap rate may change, so that the fraction of salable first quality product is reduced. Third, whatever biases, prejudices, or fears, whether well founded or not, that some foamers might have concerning the use of methylene chloride can be reflected in α. Last, to the extent that some additional capital inputs are required, such as improved ventilation, these effects can also be captured in this weighting factor.

The above equation can be solved for an equilibrium condition, and this solution yields a value of 1.062 for α. This can be interpreted to mean that all of the various quantifiable and non-quantifiable factors that have been identified above (plus others that have not) result in about a 6 percent* weighting against methylene chloride use in comparison to what the blowing agents alone would cost. This can be thought of as the additional costs of using methylene chloride that are perceived by foamers that presently use CFC, and whose circumstances are such that they are right at the margin of shifting. Those foamers who presently use methylene chloride have an α value less than 1.062, and there are CFC using foamers whose perceptions of α is much larger than 1.062.

Estimating the costs to foamers that convert requires that the value of α be estimated. As might be expected from the components of this factor, data are unavailable. Therefore we have made aggregate estimates. For

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*Six percent derives from the material costs of a super soft formulation where the CFC represents 13 percent of the material costs. The value of α depends upon the fraction of material costs that are represented by CFC. For a medium softness foam, CFC represent about 5 percent of material costs, and α is about 1.02.

large foam plants, where more technical support can be expected, we have estimated that $\alpha = 1.125$, or that the weighting against methylene chloride is about twice the equilibrium value. For small foam plants we have estimated that $\alpha = 1.2$. This implies that small plants would convert to methylene chloride when their material costs were about 20 percent higher due to using CFC.

RECOVERY AND RECYCLE

Recovery and recycle of the CFC appears technically feasible for both slabstock and molded foams, but is not practiced today because of some technological unknowns that affect capital costs of the equipment and because of uncertainties surrounding the efficiency with which the emitted CFC could be collected. In the previous discussion of CFC recovery, we noted that recent tests made in foam plants had shown that at least one plant presently collected slightly more than half of the CFC inputs in the existing ventilation system. Since these systems are not designed primarily for CFC collection, and since the systems are not sophisticated, complex, or costly, it is reasonable to assume that an average collection/adsorption efficiency of 50 percent can be expected. This assumption will be used in the estimates that follow.

Investment

The capital cost of a carbon adsorption recovery recycle system is usually quoted F.O.B. the manufacturer, and excluding installation. Vic Manufacturing, of Minneapolis, Minnesota, has stated that an allowance of 60 percent of the F.O.B. factory price is ample for transportation and installation of a unit. No one in the industry disputes this estimate, and therefore we estimate that the unit installed capital cost of recovery/recycle equipment is 1.6P, where P is the manufacturer's unit price per cubic foot per minute (CFM) of gas to be treated and the complete cost is 1.6(P)(CFM).

The price of carbon adsorption units is generally in the range of $6 - 12 per CFM, but because of the complication of the trace gases, it is agreed that this range may be too low for a flexible foam plant. The actual range is open to speculation, but Vic, for one, does not feel that the additional equipment will be very expensive. One estimate made by Vic together with a pessimistic party, suggested

$35 ± 10 per CFM. No one has suggested a price greater than $45 per CFM. For this exercise we will adopt a range of $15 to $45 per CFM as the manufacturer's unit price, and 1.6 times this for the installed capital cost to the foamer. The carbon adsorption beds must be sized to handle the entire exhaust gas stream. Since the capital cost is a linear function of the size of the exhaust gas stream, it is obviously desireable to minimize the exhaust rate. We have not estimated how low it could be; this involves the subject of TDI, which is a separate issue. Rather, we will use 20,000 CFM as an adequate, if not abundant, exhaust rate. DuPont found exhaust systems as small as 2500 CFM, and our plant visits found one system that was at least 30,000 CFM. This latter system was at a rather small plant, and the plant manager commented that their exhaust was strong enough that it sometimes sucked flecks of foam off the surface of the freshly forming bun. In our plant visits we were unable to detect any particular relation between exhaust system size and equipment size, and it was clear that exhaust system capacity is inexpensive, and is generally used lavishly so as to avoid TDI vapor concentrations. The use of 20,000 CFM as a "standard" exhaust system size will overstate capital costs somewhat, and will perhaps bias the analysis slightly in favor of large foam plants (large foam plants sometimes, but not always, have larger equipment). The installed capital cost can then be estimated to be 1.6 (20,000)P, or for values of P from $15 to $45 between $480,000 and $1,440,000, with a midpoint of $960,000.

Operating and Maintenance Costs

A carbon adsorption recovery system is a relatively simple piece of equipment that is mostly automatic in operation. The use of carbon adsorption systems in coin operated dry cleaners attests to the simplicity and reliability of the equipment. The major operating cost is for steam, that is used to desorb the CFC from the carbon bed. The cost of this has been estimated by Vic to be about 1.4 cents per pound of recovered CFC. Requirements for operating labor appear minor and maintenance appears limited to annual lubrication of motors and occasional changing of the carbon bed. To allow for this, we have estimated $7600/year. We also include insurance at 2 percent of the

capital cost.

Annual operating costs can then be estimated as (0.014)(0.5)C + 0.02 K + 7600, where K = capital cost. For a unit that costs $960,000 (the midpoint of the capital cost range), operating and maintenance costs are 0.0007C + 26,800 dollars per year.

Return on Investment

We attempted to determine what kind of return on investment would be necessary to attract foamers to use recovery and recycle equipment, but were unable to generalize what we learned. Typically, small foamers are uninterested. One small to medium foamer alleged that he would not install anything on his foam line if he didn't recover the capital cost in six months. Other small to medium sized foamers were clearly uncomfortable at the thought of a capital investment, and stated that the foam business inherently had so much uncertainty for them that they were unable to think about investments that might require several years to recoup.

Large foamers tended to look at the question objectively and with the attitude that they expected to be in business for a long time. But they still were unable to describe to us what return they would require in order for equipment to be attractive, often stating that there were other criteria besides rate of return, but being rather vague about what these criteria might be. In the last analysis, we can conclude only that small foamers would be uninterested except at extremely high rates of return, and that large foamers would be attracted if it appeared to be a reasonable financial investment. To test the attractiveness of recovery/recycle units, we have solved for the capital cost that will obtain by discounting the annual stream of returns, and have done this for several conditions of equipment life and rate of return. The equation used is

$$\text{investment} = \text{annual return}\left[\frac{1}{(1+i)^n}\right]$$

where i = rate of return
n = life of equipment
annual return = pounds of CFC recovered per year multiplied by the CFC value

*The equipment would physically last longer than 15 years.

The annual return multiplier in brackets above can be solved for values of n of 5, 10, and 15 years,* and values of i of 10, 20, and 30 percent. The extremes are a return of 10 percent over 15 years, which, if acceptable to a firm might be viewed either as philanthropic on their part, or accepted only because they had no other option to stay in business, and the return of 30 percent over 5 years. The latter is not as severe as a six month return of investment, but it is still a high rate. The factors themselves are as follows:

	n		
i	5	10	15
10%	3.74	6.14	7.61
20%	2.99	4.19	4.67
30%	2.44	3.09	3.27

The annual return can be represented as the value of the recovered CFC less the operating and maintenance costs of the recovery equipment. Thus,

$$\text{annual return} = 0.5\ P_c C - [0.5(0.014)C + 0.02K + 7600]$$

where K = capital cost of the recovery equipment, and the fraction of the CFC recovered = 0.5

For a market price, P_c, of CFC equal to 34 cents/pound,

$$\text{annual return} = 0.163C - 0.02K - 7600.$$

The investment that is equivalent to the discounted stream of annual returns is in turn equal to

$$K = k[0.163C - 0.02K - 7699].$$

Solving this equation for various values of k produces the following results:

$k = 7.61$ (15 years, 10%) $K = 1.076C-50196$

$k = 4.19$ (10 years, 20%) $K = 0.63C-29382$

$k = 3.09$ (10 years, 30%) $K = 0.474C-22117$

$k = 2.44$ (5 years, 30%) $K = 0.38C -17681$

Using these equations allows us to plot curves that relate the investment to the amount of CFC used per year. These appear in Fig. 1 for several cases, including the extremes. Fig. 1 also incorporates horizontal lines that represent our estimate of the range of cost of the equipment itself, as derived from the estimates of $15 to $45 per CFM.

Small and medium foam plants, using up to 350,000 pounds of CFC per year cannot justify recovery and recycle at current CFC prices and even the most lenient financial demands on their investment. But large foam plants, using one million pounds or more of CFC, are in a much different position, and there are several combinations of equipment prices and rates of return that might make recovery/recycle attractive to them at today's CFC prices.

There are three ways to make recovery and recycle more attractive; to lower the unit cost of the recovery equipment, in terms of dollars per CFM, to reduce the exhaust system capacity, in CFM, or to increase the value of the recovered CFC. The first two of these are subject to constraints that limit the depth of analysis that can be performed here. The last is much more amenable to analysis, and its effect is easily tested. Fig. 2 displays the same information as the previous figure, but for a CFC market price of 68¢/pound, or double the assumed present price. Here the leverage of the CFC market price is quite apparent. What might have been of only casual interest to large foam plants at a CFC price of 34¢/pound now becomes much more attractive, and would become very interesting at capital costs of $30/CFM or lower. Also, whereas at a CFC price of 34¢/pound, only the large foam plants might show interest, at 68¢/pound plants using as little as 500,000 pounds of CFC might be interested. This price is still insufficient to attract foamers whose plants use in the range of 250,000 pounds of CFC per year, or the smallest plants, which use about 100,000 pounds per year.

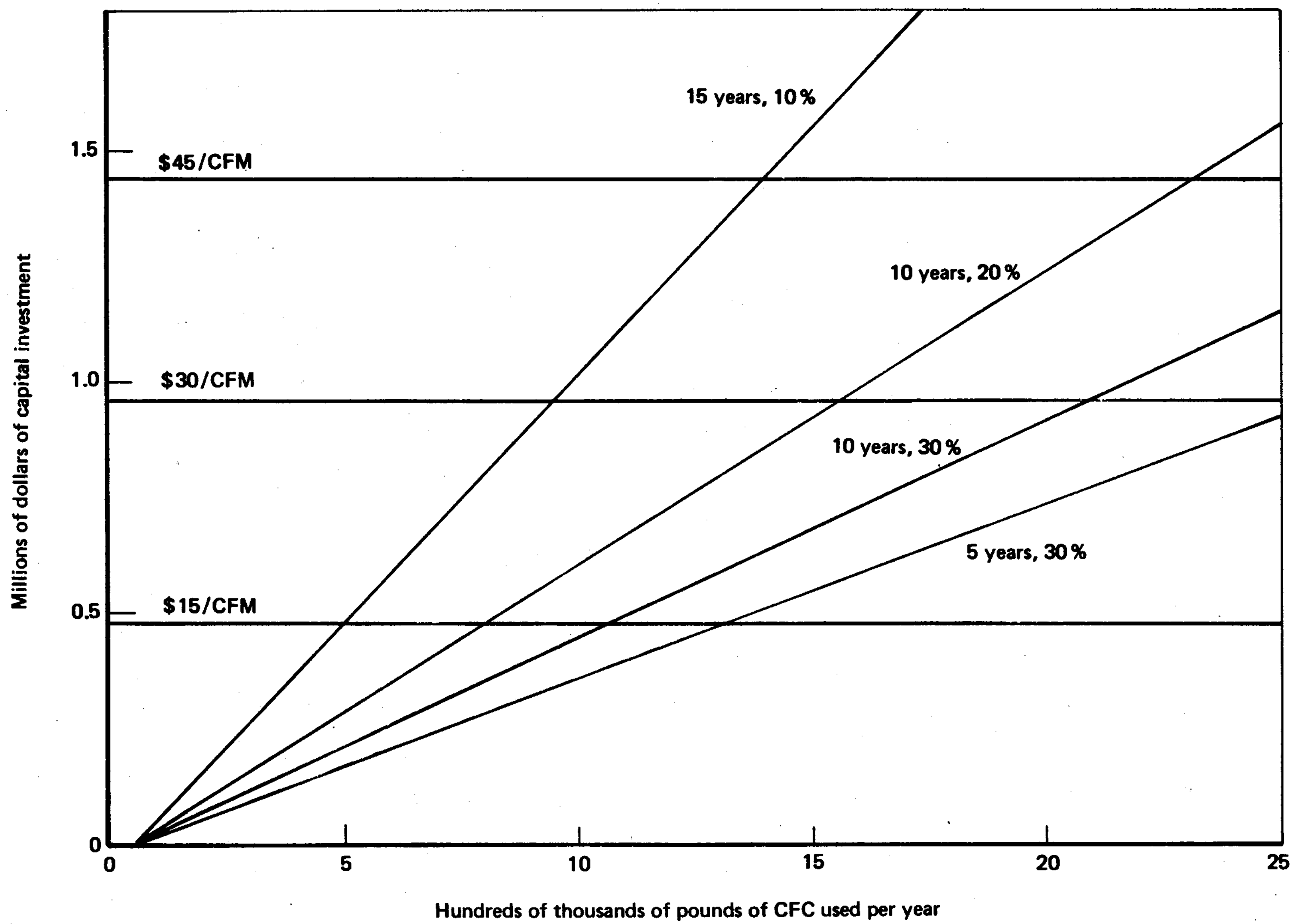

Fig. 1 — Investment—return relationships for CFC recovery / recycle equipment at CFC market prices = 34¢ /lb

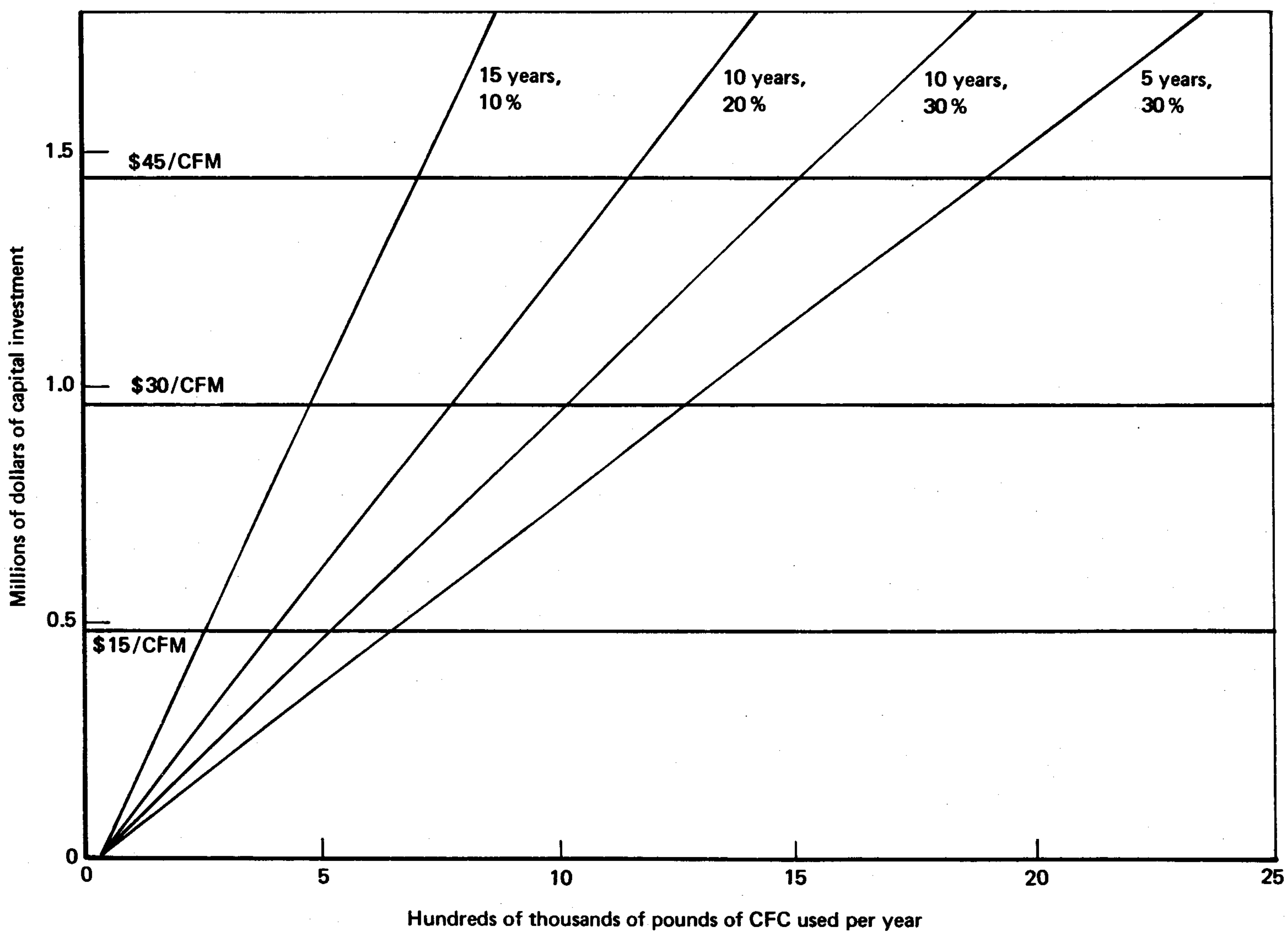

Fig. 2 — Investment – return relationships for CFC recovery / recycle equipment at CFC market price = 68¢/lb

One last chart has been prepared to illustrate the effect of a CFC market price of $1.50 per pound, and appears as Fig. 3. At this price there now appears to be some potential to attract foamers whose plants use as little as 250,000 pounds of CFC per year. The very large plants find the recovery/recycle process extremely attractive, and depending upon the capital costs, even plants using 500,000 pounds per year might be strongly motivated towards the process. The smallest plants- -those using about 100,000 pounds per year- -are still unattracted to the process, and to create favorable economic conditions for these plants to recover their CFC would require very high CFC prices.

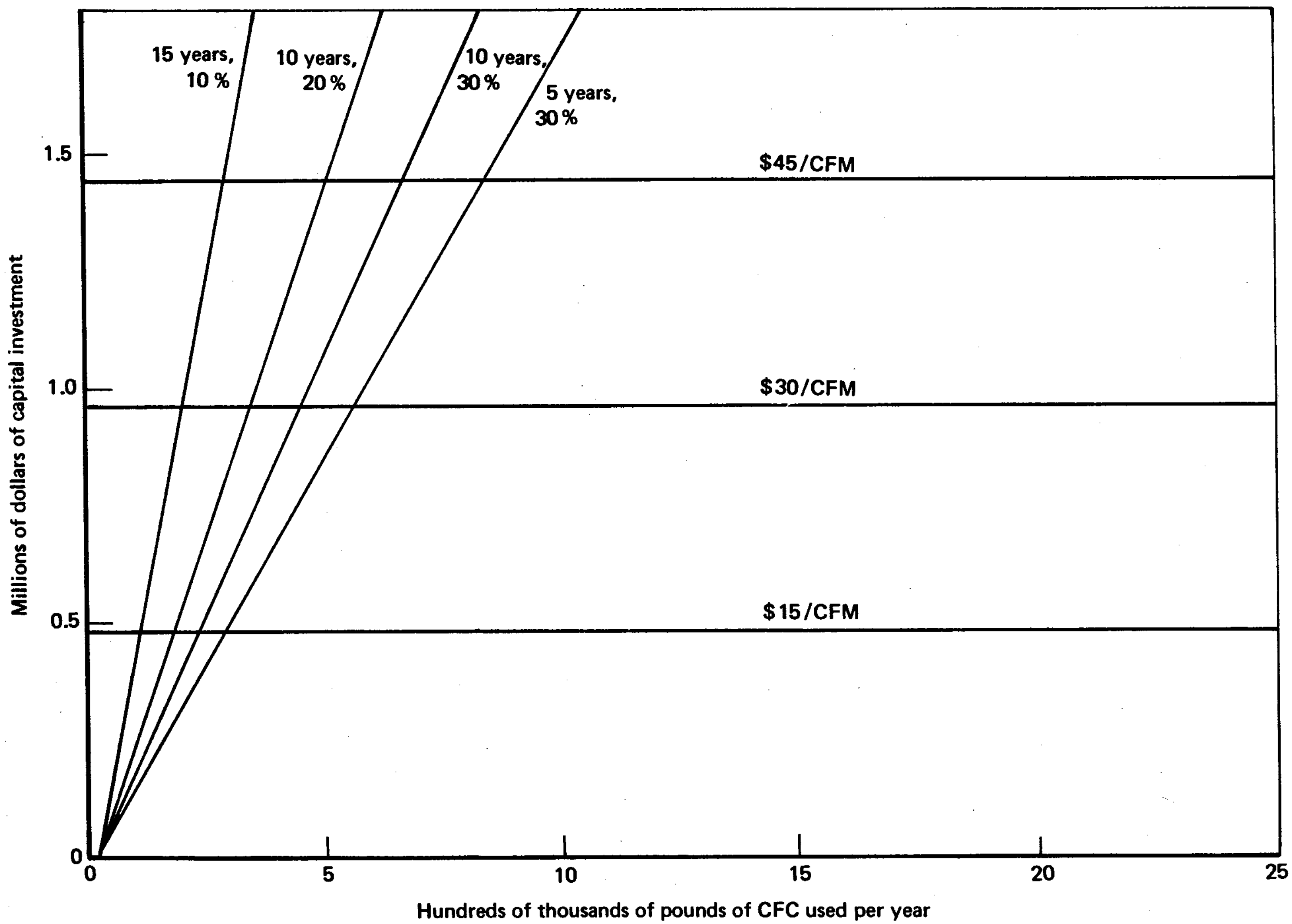

Fig. 3 — Investment – return relationships for CFC recovery / recycle equipment at CFC market price = $ 1.50 / lb

VII. ESTIMATION OF CFC DEMAND SCHEDULES

The previous section has dealt with the general economics of CFC substitution and CFC recovery and recycle. The principles developed there may be expanded to estimate what the actions of foamers might be to increases in CFC prices that are deliberately intended to reduce CFC use. This involves the synthesis of a CFC demand schedule, and is based upon the estimated economics of the technical options that are available to the foamer, and upon the structure of the foam industry. The demand schedule estimation assumes that any foamer will act to minimize his costs. The way in which he does this will depend upon his size (in terms of annual CFC use), the relative costs of the technical options available to him, and the price of CFC-11.

DISTRIBUTION OF CFC USE BY PLANTS

For the purpose of estimating the demand schedule, the data presented in Section II can be synthesized into a size distribution of foam plants. We first distinguish five types of flexible foam production facilities: large and small molded plants, and large, medium, and small slabstock plants. In addition, we assume that slabstock plants produce a 50-50 mixture of medium-soft and soft CFC blown foams. Table 9 illustrates the distribution used.*

CHOICE OF TECHNICAL OPTION

These have been treated in generalities in the previous section. Here we assume that any single foam plant will respond to any increase in CFC prices by acting to minimize its costs, by selecting a proper technical option.

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*While the actual size distribution of plants is somewhat more diverse than Table 9 indicates, these data appear to be a reasonable summary of the variety of plants in the industry and simplify the demand schedule estimation procedure considerably.

Table 9

APPROXIMATE DISTRIBUTION OF CFC USE PER PLANT
BY TYPE OF FLEXIBLE URETHANE FOAM

Type of Foam	CFC Use Per Plant (thousands of pounds)	Share Of Total CFC Use (percent)
Molded Foam		
Large plants	2500	20
Small plants	500	16
Slabstock		
Large plants	1200	34
Medium plants	225	18
Small plants	150	12

SOURCE: Based on Tables 2, 4 and industry sources.

Essentially, the estimation procedure involves two steps. First, production costs are estimated for each technical option that might be adopted by foam producers at higher CFC prices. Because the costs of these alternative production processes differ in their sensitivity to higher CFC prices, and involve different levels of initial capital outlays, the least-cost option for a firm depends upon the expected CFC price. The second step simply involves determining which option minimizes production costs, *given* the regulated price at which CFC-11 is expected to stabilize.

When confronted with higher CFC prices, the possible responses of foam producers include:*

1. Simply pay the higher CFC price;
2. CFC recovery and recycle;
3. Conversion to alternative blowing agents; and
4. Conversion to alternative blowing agents where feasible, with recovery of both CFC and the alternative blowing agent.

*We recognize, but do not analyze, the option of going out of business.

Because the adoption of any of these options is unlikely to affect significantly a foam producer's costs of labor, capital, and other nonmaterial inputs, the demand analysis focuses on material costs. For the responses listed above, annual material costs are described in equations (1) to (4), respectively (Table 10 contains the definitions of all variables).

$$(1) \quad TC_1 = [P_c C + P_m M]$$

$$(2) \quad TC_2 = [P_c(1-e)C + beC + P_m M + 0_r] + \lambda K_r$$

$$(3) \quad TC_3 = [(P_c 0 + P_m M)f + (P_a A + P_m M)(1-f)\alpha]$$

$$(4) \quad TC_4 = [(P_c(1-e)C + beC + P_m M)\ f + (P_a(1-e)A + beA + P_m M)(1-f)\alpha + 0_r] + \lambda K_r$$

In equations (1) to (4), the bracketed terms describe the cost of materials plus annual labor and insurance costs associated with CFC recovery. The unbracketed term, λK_r, refers to the amortized capital expenses for the option, where λ is a discount factor determined by the investment criteria of the firm. The capital expenses appear in these equations for material costs because the cost of the recovered blowing agent includes amortization of the capital equipment with which it is recovered.

As an illustration, consider the alternative costs of production for a flexible urethane slabstock producer manufacturing a super soft foam. In this case, the alternative blowing agent is methylene chloride, which can be used to produce all but 25 percent of a slabstock producer's output on average. Moreover, the use of this chemical is presently unattractive, as reflected in the value of α.

The discount factor λ is based on a 10 year average life for equipment and 20 percent pretax annual opportunity cost of capital (or equivalently a 4.2 year payback period requirement). Because 15 percent less methylene chloride than CFC is required to produce a given amount of foam (ignoring scrap), we also have A=0.85C. Finally, available evidence indicates that at the current CFC price of \$0.34 per pound,* CFC accounts

*Blowing agent prices appear to vary from producer to producer. As a base case, the prices of CFC and methylene chloride are assumed to be \$0.34 and \$0.22 per pound. Methylene chloride consumption by the flexible

for about 13 percent* of total material costs; this implies the cost of non-blowing agent materials is $P_m M = \frac{0.34C}{0.13}$ 0.87. = 2.28C/yr.

Table 10

VARIABLE DEFINITIONS FOR ESTIMATING CFC DEMAND
SCHEDULES IN PLASTIC FOAM MARKETS

Variable	Definition
TC_i	Materials cost of ith option (i=1,..,4).
P_c	CFC price
P_a	Price of alternative blowing agent
P_m	Price of non-blowing agent materials
C	Quantity of CFC use
A	Quantity of alternative blowing agent
M	Quantity of non-blowing agent materials
K_r	Initial capital costs for CFC recovery
O_r	Other annual costs for CFC recovery
λ	Discount factor
e	Fraction of CFC reused under CFC recovery
b	Operating cost of CFC recovery unit per pound of recovered CFC
α	Material cost weighting factor of conversion to alternative blowing agent ($\alpha \geq 1.0$)
f	Fraction of CFC use that technically cannot be converted to alternative blowing agent

foam industry is a small fraction of total methylene chloride consumption. We have assumed that its price will not change as a result of CFC price changes.

*This value is different for less soft foams, and has been properly used in development of the demand curves. The example used here is presented to demonstrate the technique.

Based on these observations and the cost data presented above for flexible slabstock we have the following parameters for equations (1) to (4):*

p_a = \$0.22	b = 0.014
K_r = \$960,000	α = 1.125
O_r = \$26,800	f = 0.25
A = \$0.85C	$P_m M$ = \$2.28C/year
λ = 0.24	
e = 0.014	

Substituting these values into equations (1) to (4), total material costs (in millions of dollars) for a flexible urethane foam producer are:

$$\text{(1a)} \quad TC_1 = (p_c + 2.28)C$$

$$\text{(2a)} \quad TC_2 = (0.5\ p_c + 2.29)C + 0.256$$

$$\text{(3a)} \quad TC_3 = (0.25\ p_c + 2.65)C$$

$$\text{(4a)} \quad TC_4 = (0.13\ p_c + 2.58)C + 0.256$$

Equations (1a) to (4a) describe material costs under each respective option as a function of the CFC price and the amount of CFC the firm would use in the absence of regulation. Figure 4 illustrates these annual material cost curves for a large flexible slabstock plant, where the value of C is 1.2 million pounds per year (see Table 9).

The kinked bold line at the bottom of the figure shows which option is characterized by the lowest material costs over several ranges of the price of CFC-11. Not surprisingly, at CFC-11 prices near the current level (\$0.34 per pound in 1976 dollars), the most profitable

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*Note that the value of α corresponds to a large slabstock plant. For smaller foam plants a value of α=1.2 is assumed

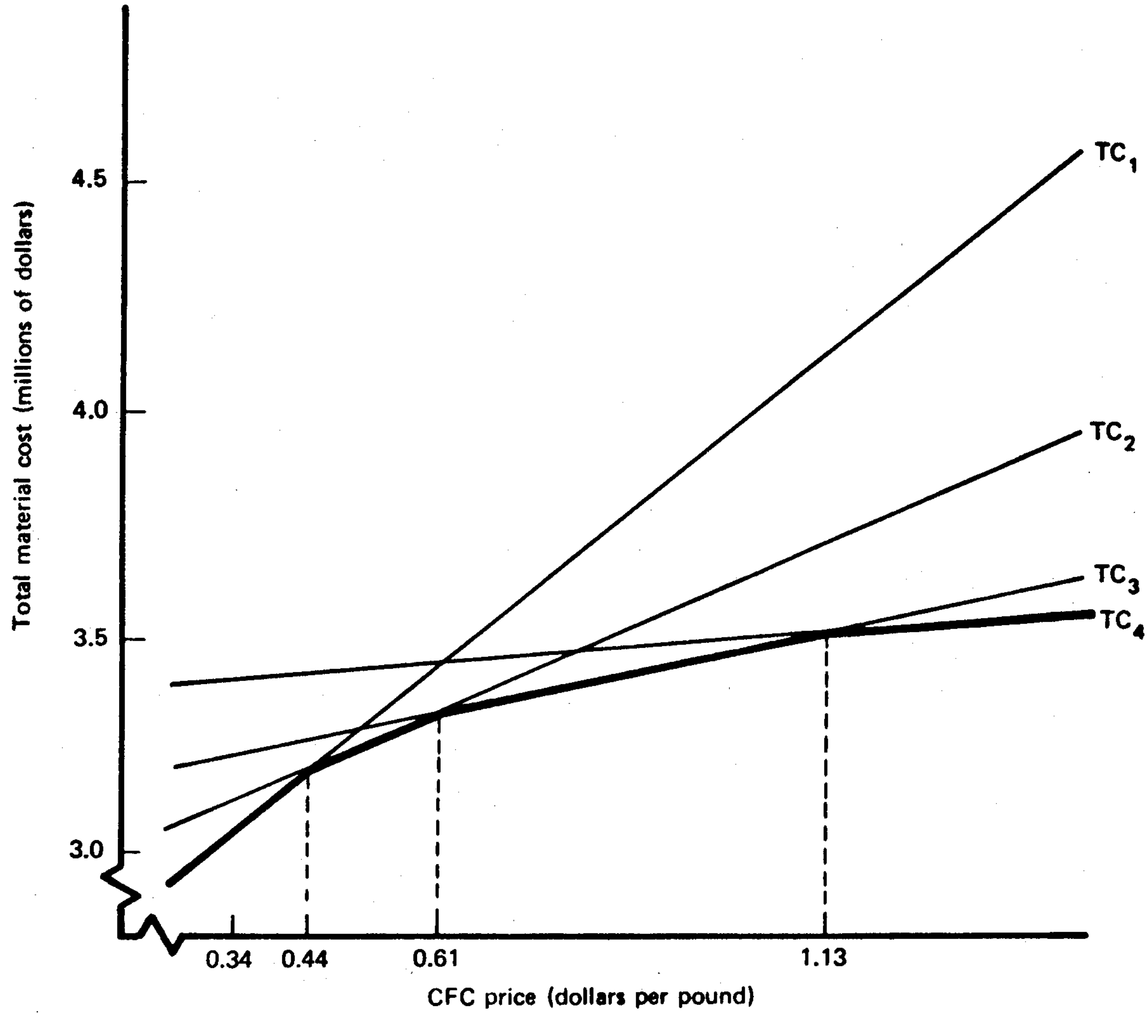

Fig. 4 — Annual material costs for a large flexible slabstock plant

action for the firm is simply to pay the higher price. However, material costs rise rapidly under this option as the price of CFC is increased by regulation.* If the regulated price is between 0.44 and 0.61, the least-cost response of the firm is CFC recovery. While CFC recovery requires a large initial investment, this cost is more than offset by the savings realized by the firm because it purchases less CFC blowing agent. Similarly, if the regulated CFC-11 price is between $0.61 and $1.13 per pound, the firm's most profitable course of action is to convert to methylene chloride. Above the price of $1.13 per pound, the firm further reduces its use of CFC by conversion to methylene chloride for the products that can be produced with this chemical and using recovery equipment to reuse both CFC and methylene chloride.

The exercise above is illustrative of the process used to determine the least-cost options for each plant. In practice, the parameters of the model change for each size of plant and type of foam produced. Development of the demand schedules relied upon a rigorous treatment of each of these, according to the method just described.

RESPONSES TO HIGHER CFC PRICES

For producers of molded flexible urethane foam, the only possible response to higher CFC prices (other than reduced output levels) is to pay the higher price of CFC recovery. On the basis of the recovery costs described above, recovery and recycle appears cost effective at or near current CFC-11 price levels for large molded plants, which use extremely large amounts of CFC-11.**

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*That is, the slope of TC_1 is greater than the slope of the other cost functions.

**Recovery appears economical at current prices for these large CFC users even at the upper bound estimate of capital costs ($1.44 million per plant). There are several possible explanations of why recovery does not occur at the present time. First, firm managers may be uncertain about what overall recovery efficiencies are actually achievable and about actual volumes of exhaust gas to be treated. Second, some cost variables may have been omitted from the analysis. Third, and perhaps most important, the uncertain regulatory climate in the recent past may have discouraged recovery efforts. For example, despite the seemingly attractive economics, recovery would be discouraged if firms anticipated

For smaller producers of molded foam, the total value of recovered CFC is only 20 percent of that for large CFC users, and CFC recovery will probably not occur unless the price of CFC-11 exceeds $1.04 per pound.

For large slabstock plants, no emissions reduction activity is expected at long run CFC-11 prices below $0.44 per pound. Above this price level, reducing CFC use (and emissions) is a profitable activity. From the cost parameters presented above, at prices from $0.44 to $0.61 per pound, all large slabstock plants would minimize production costs by employing CFC recovery equipment. If firms expect a regulated price of CFC-11 from $0.61 to $1.13, methylene chloride conversion (rather than CFC recovery) will occur in large plants that primarily produce soft foam products, reducing emissions by 75 percent. However, for large slabstock plants that primarily produce medium soft foams, CFC recovery always results in lower costs than methylene chloride conversion in the range of CFC prices considered in this study. Finally, if firms can recover methylene chloride as well as CFC-11 (as available evidence suggests), the analysis suggests that at prices above $1.13 per pound large slabstock plants that produce softer foams would convert to methylene chloride where possible and purchase recovery equipment in order to reuse both auxiliary blowing agents.

For smaller slabstock producers, CFC recovery is an extremely unlikely outcome of higher CFC prices regardless of the type of foam produced because of their relatively low CFC use levels per plant.*
Instead, we expect small slabstock producers to respond to higher CFC prices by switching blowing agents. However, because of the material

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a future ban on CFC blowing agents, as occurred in the aerosol regulations, or if substantial subsidies were anticipated for future purchases of recovery equipment. In any case, all available evidence strongly suggests that CFC recovery in large molded foam plants would be among the first responses observed as the CFC price increases.

*For smaller slabstock producers, CFC recovery does not result in lower production costs than methylene chloride conversion at any CFC price, on the basis of the cost parameters defined above. If a small plant cannot convert any of its output to methylene chloride, CFC recovery would be induced at a CFC price of $2.29 for medium slabstock plants and $3.42 for the smallest slabstock plants in Table 9.

and other costs associated with methylene chloride, conversion by small plants that produce softer products is not expected unless the CFC price exceeds $0.68 per pound. At this price, these producers convert 75 percent of their CFC-blown production to methylene chloride and are assumed to incur higher prices for the remaining CFC. For small plants that primarily produce medium soft foam, conversion to methylene chloride is not expected unless the CFC price reaches $1.52 per pound.

Finally, higher CFC prices would also induce improved collection efficiencies for CFC recovery in both molded and slabstock plants. Although existing plants appear to collect a significant fraction of CFC use at central points in their ventilation systems, plants have not been designed with this purpose in mind. Higher CFC prices would create strong incentives to recycle as much CFC-11 as possible, given that a firm employs recovery equipment. While exact information on the costs of improving collection efficiencies is unavailable, in some cases relatively modest capital costs may be involved. However, even assuming that capital costs are high leads us to expect that a CFC-11 price of about $1.50 would be sufficient to induce an increase in overall recovery efficiencies to 80 percent of CFC use.*

Table 11 presents the demand schedule for CFC use in flexible urethane foams, based on the above analysis and assumptions. According to the analysis, an increase in the CFC price of only 10 cents per pound will reduce CFC use by an estimated 27 percent. If CFC-11 prices were to double, CFC use in flexible foam products would decline by over 42 percent, with most of the emissions reduction activity occurring in large foam plants. Because flexible foams are prompt emitters, the annual use reductions in Table 11 equal annual reductions in CFC-11 emissions.

The increase in CFC-11 prices required to induce the use of a technical option measures the cost of the option per unit reduction in CFC-11 use. Thus, the first technical option to be induced, recovery in large molded slabstock plants, reduces use by 12.6 million pounds at a cost of

*For a molded foam producer using 500,000 pounds of CFC annually, modifying the plant to achieve this higher collection efficiency at a CFC price of $1.50 will be profitable so long as the capital costs involved are less than an estimated $920,000.

Table 11

CFC-11 DEMAND SCHEDULE FOR FLEXIBLE URETHANE FOAM: 1980 AND 1990

(millions of pounds)

CFC-11 Price ($ 1976 per pound)	Induced Activity[a]	1980 CFC Reduction[b]	1980 Total CFC Use[c]	1990 CFC Reduction[b]	1990 Total CFC Use[c]
$0.34	None	-	46.8	-	71.5
$0.44	Large MD and all large SL plants recover	12.6	34.2	19.3	52.2
$0.61	Large SL, SF plants convert	2.0	32.2	3.0	49.2
$0.68	Smaller SL, SF plants convert	5.3	26.9	8.0	41.2
$1.04	Small MD plants recover	3.7	23.2	5.7	35.5
$1.13	Large SL, SF plants recover and convert	1.0	22.2	1.5	34.0
$1.50	Improved collection efficiency	8.0	14.2	12.3	21.7
$1.52	Smaller SL, MF plants convert	5.3	8.9	8.0	13.7

SOURCE: See text for explanation of calculations. Estimates based on distribution of CFC use in Table 9.

[a]Abbreviations: MD denotes molded foam, SL donotes flexible slabstock, SF denotes soft slabstock foam, and MF denotes medium soft slabstock foam.

[b]Shows incremental reduction induced in price ranges shown.

[c]Shows total CFC-11 use at indicated price level.

just 10 cents per pound of reduction. However, achieving further reductions imposes increasingly higher costs per unit reduction in CFC use. For example, the cost of the last technical option that is induced by higher prices (methylene chloride conversion by small slabstock plants producing medium soft foam) is $1.18 per pound

In part, the higher costs required for each additional emissions reduction activity reflect the differential economic impact of restrictions on CFC use for large and small foamers. Because of their lack of sufficient technical expertise for using methylene chloride and lack of large size for CFC recovery, small plants find it relatively costly to reduce CFC use. Thus, while large foamers find it cost-saving to substitute away from CFC at relatively low CFC prices, small foamers will absorb the full impact of higher CFC prices until the CFC-11 price increase is substantial.

The demand schedule of Table 11 can be used to derive information regarding the use of methylene chloride. At a CFC price of $0.68, we estimate methylene chloride use will be at least 11 million pounds higher than in the baseline case in 1980 and nearly 17 million pounds higher in 1990. However, at prices in excess of $1.13 for CFC-11, methylene chloride may be recovered along with CFC-11 by large slabstock plants. In this CFC price range, methylene chloride use is higher than in the baseline forecast, but only by about 8 million pounds in 1980 and 13 million pounds in 1990. Finally, at CFC-11 prices in excess of $1.52, we estimate that methylene chloride use will increase by about 12 million pounds in 1980 and by over 18 million pounds in 1990.*

Control Candidates

The two technical options for reducing CFC-11 use and emissions from flexible foams--recovery and recycle and methylene chloride conversion--are discussed here as candidates for mandatory control policy in contrast to the economic incentives described above. The first of the options could be mandated; as explained below, this analysis presumes

*Note that this estimate differs from that on page 32, which referred to a methylene chloride mandate. Also note that since the consumption of methylene chloride is only a small fraction of total

that CFC recovery and recycle would be implemented in the absence of any other regulatory restrictions limiting the use of methylene chloride, thus allowing foamers who would find the CFC recovery mandate especially costly to avoid the mandate by converting to methylene chloride. For reasons given below, mandated methylene chloride conversion is not included as a control, though the implications of required conversion are spelled out here.

Mandated Recovery and Recycle

Recovery and recycle could be successfully mandated: The mandate appears enforceable because once each plant has made the investment in recovery equipment it is cost-saving to use the equipment rather than to let it stand idle; hence, enforcement consists of making sure each plant acquires the necessary equipment. The mandate would be effective in reducing CFC-11 emissions by 1990 because annual use equals annual emissions in the flexible foams product area. There are also sufficient data about recovery and recycle to make a reasonable judgment about the costs and effectiveness of a recovery mandate. Moreover, the recovery option is technically feasible for all types of foams, so a recovery mandate would not require exemptions in order to avoid eliminating the production of certain foams.

A CFC recovery mandate for flexible foams could be implemented as a new source standard, requiring compliance only in plants constructed after a specified date, or as a retrofit standard, requiring compliance by existing plants as well. However, new source standards are unlikely to be an effective means of controlling emissions from flexible foam plants. These plants typically operate for only one to five hours per working day and appear capable of significant increases in output levels. Because new source standards dramatically increase production costs in new plants relative to existing facilities, a likely outcome is that existing foam plants would be operated more hours than otherwise and industry growth would occur primarily through expansion of output in existing plants where emissions controls are not required.

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methylene chloride use in the U.S., prices would not be expected to rise solely because of this increase in use.

In contrast, mandatory controls requiring recovery in existing as well as in new plants do not increase production costs in new foam plants relative to old plants, and no incentives are created to avoid new plant construction in order to circumvent the intent of the regulation.* As a result, while new source standards would have little impact on pre-1990 CFC emissions in this industry, retrofitting could significantly reduce emissions levels. The following analysis concentrates on mandatory controls for both existing and new plants.

Under a CFC recovery mandate, producers of molded flexible urethane foams would purchase recovery equipment and reduce emissions by about 50 percent. For large molded CFC users, recovery currently appears economical (or nearly so) and no compliance costs for the regulation are imputed to these firms. For smaller molded foam plants, a CFC recovery mandate increases the fixed costs of production by an estimated $256,000 annually (including amortized capital expenses, insurance, and other costs) and reduces material expenditures by only $81,000, resulting in a net cost to each plant of approximately $175,000 annually, or $0.70 per pound of CFC emissions avoided.

For large flexible slabstock plants, the use of mandated CFC recovery devices also increases fixed production costs by $256,000 annually. However, because of the greater quantities of CFC recovered, material expenditures are reduced by nearly $196,000, and the net annual costs of the mandate are estimated at about $60,000, or $0.10 per pound of emissions avoided.

On the basis of the earlier demand analysis, firms that produce flexible slabstock in smaller plants will not respond to a recovery mandate by purchasing recovery equipment. Rather, if allowed to do so, they will convert foam lines to the use of methylene

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*Currently, several factors, such as transportation and warehousing costs, constrain optimal plant output levels. A CFC recovery mandate increases the fixed costs of production while reducing variable costs by substituting reclaimed for virgin CFC. Consequently, optimal plant output levels under the mandate would increase slightly (see R-2524-EPA) and there would be fewer flexible urethane foam plants than in the baseline case. However, this does not imply that plant closings would occur. Rather, fewer plants would be constructed to meet the anticipated growth of the industry.

Table 12

EFFECTS OF MANDATED CFC RECOVERY IN FLEXIBLE URETHANE FOAM PLANTS

Type of Foam, Plant size	Emissions Reduction (millions of pounds)			Total Compliance Costs (millions of dollars)			Cost per pound[c] (dollars)
	1980	1990	1980-1990[a]	1980	1990	1980-1990[b]	
Molded	8.3	12.6	114.7	$2.4	$3.8	$21.3	$0.31
Large Plants[d]	4.6	7.0	63.8	--	--	--	--
Small Plants	3.7	5.6	50.9	2.4	3.8	21.3	0.70
Slabstock	18.2	27.9	253.8	8.5	13.2	72.0	0.47
Large Plants	7.9	12.1	110.3	0.7	1.2	6.6	0.10
Medium and Small Plants[e]	10.3	15.8	143.5	7.8	12.0	65.4	0.76
Total	26.5	40.5	368.5	10.9	17.0	93.3	0.41

SOURCE: See text for explanation of calculations. Assumes mandate applies to existing and new plants, and no restrictions on methylene chloride use. Cost estimates are in constant (1976) dollars.

[a]Cumulative emissions reduction from 1980 to 1990, inclusive.

[b]Present value of annual 1980 to 1990 net costs, discounted at 11 percent.

[c]Calculated from individual plant data.

[d]Recovery assumed economic at or near current CFC prices.

[e]Emissions reductions and estimated costs based on methylene chloride conversion, rather than CFC recovery. Estimates include plants producing both medium soft and soft flexible foams.

chloride. For softer foam output that can be converted, the costs of substituting methylene chloride may be as high as $65,000 per plant annually, or $0.34 per pound of CFC emissions avoided.* For smaller slabstock plants that primarily produce medium soft products, the estimated costs of conversion are much higher, although still less than if these plants were to recover their CFC. For these plants, the recovery/recycle mandate could impose costs as high as $221,000 per plant, or $1.18 per pound of emissions avoided.

Small plants that produce flexible slabstock would probably lose any foam markets that depended on products that cannot be converted to methylene chloride at the present time. The most likely outcome is that these markets would be supplied by increased output from larger plants. Consequently, this analysis does not estimate the costs of forgone production of these products.

Table 12 summarizes the costs of mandated CFC recovery for the flexible urethane foam industry, assuming that small slabstock plants convert to methylene chloride. With an overall recovery efficiency of 50 percent, the mandate could reduce annual emissions by over 40 million pounds in 1990 and cumulative emissions by nearly 370 million pounds from 1980 through 1990.

Estimates of costs in Table 12 implicitly assume that the number of flexible foam plants in each category increases proportionately with industry output.** The total estimated costs of a CFC recovery mandate are $10.9 million in 1980 and $17.0 million in 1990 (in 1976 dollars), averaging about $0.41 per pound of emissions avoided. From 1980 to 1990, the present value of the estimated costs generated by the regulation are $93.3 million (discounted at 11 percent annually).

The above analysis assumes that no regulatory action is taken to discourage the use of methylene chloride blowing agents. If a

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*Based on cost assumptions presented on pages 35-38.

**Because average output per plant is likely to increase slightly, and because the net costs of CFC recovery decrease as plant size increases, the assumption of constant per plant output levels over time biases cost estimates upward.

CFC recovery mandate required that small slabstock foamers use CFC recovery, rather than convert to methylene chloride, the costs of the regulation would be higher. Assuming annual CFC use levels of 225,000 pounds for medium sized plants and 150,000 pounds for small plants, the net costs of using recovery equipment are an estimated \$1.95 and \$3.08 per pound of emissions avoided for those plants, respectively.* While the level of emissions reduction declines because only 50 percent of CFC emissions are assumed recovered, total compliance costs for these firms increase sharply to about \$17 million in 1980 and \$25 million in 1990.

In short, if a CFC recovery mandate is designed to force smaller slabstock foam plants to purchase and use recovery equipment, the net costs imposed on all smaller plants would be more than five times the total costs incurred by all other firms combined, despite the fact that the total emissions reduction of the larger plants would be twice as great. Obviously, it is unlikely that small plants could survive such an extreme cost disadvantage. Consequently, under a CFC recovery mandate combined with restrictions on the use of methylene chloride, many small plants may be forced to close. Currently, there are at least 60 plants that might be affected, located in all regions of the country. The markets previously supplied by this sector of the industry would be gained by non-foam substitute products or, as appears more likely, by larger foam plants.

Ultimately, the cost impacts of mandated CFC recovery will be born primarily by the final consumers of products that use flexible urethane foam. Although the total costs of the control strategy (assuming small slabstock plants convert to methylene chloride) are significant through 1990, the impact on prices of individual products will probably be small. In markets where foam is only one component of the final good, final product prices would probably rise by no more than 1 percent for furniture products and by much less in the transportation markets. In other cases where foam makes up a larger fraction of final product costs, such as foamed mattresses and carpet

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*Note that the costs of CFC recovery and recycle are not affected by the type of foam produced.

underlay, the relative increase in prices will be larger. The cost of the flexible foam itself would increase by less than 5 percent on average, with greater increases for smaller slabstock and molded plants than for other producers.

The employment effects of mandated CFC recovery are exceedingly difficult to estimate. However, even under the assumption of completely inelastic foam demand, the above analysis suggests that some smaller plants, which are placed at a relative cost disadvantage, may reduce employment levels or close down as foam markets are lost to larger competitors. Although total industry employment may not be significantly affected, temporary employment dislocations will almost certainly occur, affecting perhaps as many as 1,500 workers.

Mandated Methylene Chloride Conversion

At present, most molded foams and some slabstock foams cannot be made with methylene chloride. Thus, unless some foam products are exempted, a methylene chloride conversion mandate might amount to a product ban on 25 percent of slabstock foam and virtually all molded foams, which together currently account for over half of all CFC blown output. In these segments of the industry, the promulgation of a conversion mandate would result in possibly severe employment effects as well as substantial losses in terms of the value of forgone output. Because product bans are not a focus of the current analysis, we do not include the unexempted conversion mandate in the benchmark mandatory controls.

For (slabstock) foams that can be converted to methylene chloride, an effectively enforced conversion mandate would cost the affected firms a total of $13.0 million in 1980 and $19.7 million in 1990, with small plants accounting for perhaps nearly two-thirds of the total.

It is unlikely that a conversion mandate that exempts certain foams could be effectively enforced. Since an individual slabstock plant produces several different types of foams, exemptions for slabstock foams that cannot be made with methylene chloride would allow both CFC-11 and methylene chloride blowing agents to be used

in the same plant. Because the alternative blowing agents can be used on the same production line, enforcement of a regulation involving exemptions would be difficult and costly, requiring a constant threat of inspection at every plant. Consequently, the option of mandating methylene chloride conversion is omitted on the grounds that it is unlikely to be enforceable.

CONCLUSION

Flexible urethane foam plants are a significant source of CFC emissions. Total emissions from flexible urethane foam are among the largest of all nonaerosol CFC uses and may be as high as 90 million pounds of CFC-11 in 1990. Moreover, each plant represents an extremely large point source of emissions, with hundreds of thousands of pounds of CFC-11 used and emitted annually per facility.

In contrast to many other nonaerosol CFC uses, emissions from flexible urethane foam appear susceptible to regulatory action. Either CFC recovery or methylene chloride conversion could substantially reduce CFC releases to the atmosphere, and CFC recovery appears to be an enforceable candidate for mandatory controls. However, the most efficient means of reducing emissions for a flexible foam producer depends upon the characteristics of the firm, such as the level of CFC use per plant and the types of foam products produced. Thus, mandatory recovery would impose vastly different levels of costs on different firms.

The use of CFC in foam products is sensitive to the price of CFC-11. The analysis suggests that substantial reductions in use can be induced by moderate price increases, and that total industry use could be reduced by as much as 80 percent if the price of CFC-11 increased by slightly more than $1.00 per pound.

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